NATURE-BASED INFRASTRUCTURE
GLOBAL RESOURCE CENTRE

Sustainable Asset Valuation of Mangrove Restoration in Sine-Saloum, Senegal

NBI REPORT

DRAFT

IISD International Institute for Sustainable Development

Socodevi

En partenariat avec Canada

Edoardo Carlucci

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Sustainable Asset Valuation (SAVi) of Mangrove Restoration in Sine Saloum, Senegal

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Written by Edoardo Carlucci (IISD)

Photo: International Institute for Sustainable Development

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Executive Summary

The Sine-Saloum Delta, located in west-central Senegal, is a UNESCO Biosphere Reserve covering approximately 232,500 hectares, including 58,300 hectares of mangrove ecosystems. These mangroves provide essential ecosystem services such as coastal protection and fisheries, supporting the livelihoods of more than 100,000 people. The delta functions as a reverse estuary, where seawater intrudes upstream, making the area particularly vulnerable to salinization, coastal erosion, and habitat loss (WIACO, 2025).

Since the 1980s, overharvesting of mangrove wood, the expansion of rice cultivation into sensitive coastal areas, poor waste management, and climate change have intensified environmental degradation in the delta. These combined pressures have disrupted hydrological systems and accelerated soil salinization. As a result, more than half of agricultural lands are now saline, forcing many farmers to abandon rice fields and worsening poverty and food insecurity (WIACO, 2025).

Women who depend on fishing, oyster harvesting, honey collection, medicinal plants, fuelwood, and market gardening are particularly vulnerable, yet they also stand to gain significantly from mangrove restoration. Integrating ecosystem restoration with community-led management is therefore critical to safeguard the delta's ecological integrity, enhance climate resilience, and secure livelihoods (WIACO 2025).

Figure ES1. Mangroves in Senegal

Source: International Institute for Sustainable Development.

This assessment examines how flood frequency and climate change influence the outcomes of mangrove restoration over a 27-year period from 2024 to 2050. Two flood scenarios are considered based on how often extreme flood events occur (Table ES2). In the severe flood scenario, extreme floods are more frequent, occurring on average every two years. In the moderate flood scenario, extreme floods are less frequent, occurring every five years.

The analysis also considers two climate pathways[1] (Table ES3): SSP3 7.0,[2] representing medium-high emissions, and SSP5 8.5,[3] representing high emissions.

Each of the four resulting scenario combinations is evaluated under four levels of assumed infrastructure damage reduction: 2.5%, 5%, 7.5%, and 10%. These values reflect uncertainty in how effectively restored mangroves can reduce flood-related damage. The 2.5% level represents a conservative, low-protection case, while the 10% level reflects an optimistic upper limit of mangrove protection efficiency.

This approach captures the uncertainty associated with restoration success and helps decision-makers understand how variations in protective performance influence the overall viability of the project.

Table ES1. Reduction to infrastructure damage due to the protection efficiency of the mangrove restoration project

Protection efficiency	Reduction in infrastructure damage
High	10%
Medium/high	7.5%
Medium/low	5%
Low	2.5%

Source: Authors.

The analysis provides the following results based on the climate and flood scenarios:

Flood frequency regimes:

- Under moderate flood conditions, the net present value (NPV) ranges from XOF 6.47 billion at 2.5% infrastructure damage reduction to XOF 12.45 billion at 10% reduction.
- Severe flood scenarios generate much higher economic returns, with the NPV reaching XOF 24.10 billion under optimal conditions, where protection efficiency is 10%.

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[1] SSPs are scenarios that imagine different ways in which the world could evolve in the future, such as economic growth, population, technologies, or public policies. They are used to estimate how these developments may influence greenhouse gas emissions and, therefore, the climate.
[2] SSP3-7.0 corresponds to a scenario in which greenhouse gas emissions remain high throughout the century.
[3] SSP5-8.5 corresponds to a scenario in which emissions remain very high, leading to even greater warming.

- Benefit-cost ratios (BCR) remain consistently above 2.0, ranging from 2.27 to 5.71. This means that every XOF invested in mangrove restoration yields between XOF 2.27 and XOF 5.71 in avoided damage and benefits. Results show that performance improves significantly with both higher flood frequency and greater protection efficiency.
- This confirms that mangrove restoration delivers increasing returns in high-risk environments where climate hazards are more frequent and intense.

Future climate scenario:

- Under the SSP3 7.0 pathway, which assumes moderate emissions but more frequent flooding between 2024 and 2050, mangrove restoration delivers the highest economic returns. At 10% protection efficiency, the net present value (NPV) reaches XOF 13.1 billion, while the benefit-cost ratio (BCR) is 3.97.
- In contrast, the high-emissions SSP5 8.5 scenario projects higher emissions but fewer flood events within the project period. Because floods occur less frequently and later in the century, mangroves have fewer opportunities to prevent damage, leading to smaller and delayed avoided costs and therefore a lower NPV.
- Even under these conditions and with lower protection efficiency, mangrove restoration remains economically viable. With only a 2.5% reduction in infrastructure damage, the NPV reaches XOF 5.0 billion and the BCR is 2.1.
- Overall, the results show that mangrove restoration performs better under more frequent and earlier flood events, which lead to higher avoided damage and greater NPVs. This confirms that mangrove restoration remains economically viable under all projected climate scenarios.

Beyond flood protection, mangrove restoration generates a wide range of benefits and avoided costs. Job creation accounts for XOF 2.42 billion, representing 31% of total benefits, excluding avoided infrastructure damage. Essential goods and ecosystem services such as food, wood, and clean water contribute XOF 2.30 billion (30%). Enhanced agricultural and fishery yields add XOF 1.62 billion (20.6%), while carbon sequestration provides XOF 840 million (10.7%), and health improvements result in XOF 610 million in savings (7.8%).

Together, these diverse benefits strengthen livelihoods, improve community resilience, and highlight mangrove restoration as a strategic intervention with broad social and economic returns.

A gender-differentiated analysis demonstrates that women capture XOF 1.38 billion, about 29% of the total benefits, through higher agricultural income, expanded seafood harvesting, job creation, and reduced health care costs. However, restricted land and resource rights, exclusion from decision making, and limited access to finance threaten their ability to sustain these gains. Empowering women through inclusive governance structures, capacity building, and targeted financing is therefore essential to maximize both social equity and ecosystem outcomes.

The results from this assessment provide clear guidance for a range of key stakeholders engaged in Sine-Saloum's ecosystem management and development:

- **Marine conservation authorities** are encouraged to prioritize mangrove restoration as a multifunctional strategy. Restoration strengthens flood protection, improves water quality, and enhances carbon storage while generating social and economic benefits. Integrating these diverse values into adaptation budgets and planning ensures informed implementation and lasting gains for both people and nature.
- **Environmental authorities** can use these results to demonstrate progress on mangrove restoration—a priority under Senegal's National Adaptation Plan (NAP). The Natur'ELLES initiative operationalizes the plan's vision of a productive, diversified, clean, and climate-resilient coastline by tackling coastal erosion, salinization, and livelihood vulnerability through restoration in Sine-Saloum. It aligns with the plan's four pillars by: advancing nature-based coastal protection and land use management; strengthening community adaptation via livelihood diversification and reduced infrastructure exposure; improving governance through multistakeholder, inclusive decision making; and enhancing knowledge through participatory monitoring and ecosystem assessment. This assessment contributes evidence under the fourth pillar by generating localized data on adaptation effectiveness.
- **Local communities** gain tangible livelihood opportunities through mangrove restoration, including paid work in planting and maintenance, improved fishery and agricultural yields, and more diverse income sources. Ensuring community participation and shared decision making in restoration efforts is vital for equitable benefit distribution, social cohesion, and stronger adaptive capacity.
- **Private investors and financiers** can tap into multiple revenue opportunities, from higher agricultural and fish production to carbon credit generation and employment. Outcome-based financing and public-private partnerships offer effective models for expanding restoration efforts. Aligning financial incentives with ecosystem services and community well-being reduces risk and ensures fair rewards for all stakeholders.

By aligning economic incentives with ecological stewardship and social inclusion, mangrove restoration in Sine-Saloum offers a replicable blueprint for nature-based infrastructure that safeguards infrastructure, supports livelihoods, and advances sustainable development.

Table ES2. Summary table of integrated cost-benefit analysis based on flood frequency scenarios, figures in billion XOF, discounted at 3.5%

Reduction in damage to infrastructure	Reduction in damage, 10%		Reduction in damage, 7.5%		Reduction in damage, 5%		Reduction in damage, 2.5%	
Flood frequency	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**
Direct costs								
Construction costs	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Operational and maintenance costs	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37
Total costs	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**
Avoided costs								
Avoided damage to infrastructure	7.98	19.63	5.98	14.72	3.99	9.82	1.99	4.91
Avoided health-related costs	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Added benefits								
Fishery revenue	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Agricultural revenue	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Seafood harvest revenues	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Drinking water supply	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Food supply	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Wood supply	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Job creation	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Carbon sequestration	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84

Reduction in damage to infrastructure	**Reduction in damage, 10%**		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
Total benefits and avoided costs	**15.86**	**27.51**	**13.86**	**22.60**	**11.87**	**17.69**	**9.87**	**12.78**
KPIs								
Net present value (NPV)	**11.44**	**23.09**	**9.45**	**18.19**	**7.45**	**13.28**	**5.46**	**8.37**
Benefit-to-cost ratio (BCR)	**3.59**	**6.23**	**3.14**	**5.12**	**2.69**	**4.01**	**2.24**	**2.90**
Internal rate of return (IRR)	**150%**	**303%**	**135%**	**254%**	**118%**	**201%**	**95%**	**14%**

Source: Author.

Table ES3. Summary table of integrated cost benefit analysis based on SSP scenarios, figures in billion XOF, discounted at 3.5%

	Reduction in damage, 10%		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
SSP scenario	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**
Direct costs								
Construction costs	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Operational and maintenance costs	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37
Total costs	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**
Avoided costs								
Avoided damage to infrastructure	6.14	9.66	4.61	7.24	3.07	4.83	1.54	2.41
Avoided health-related costs	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Added benefits								

	Reduction in damage, 10%		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
Fishery revenue	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Agricultural revenue	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Seafood harvest revenues	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Drinking water supply	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Food supply	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Wood supply	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Job creation	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Carbon sequestration	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total benefits and avoided costs	**14.02**	**17.53**	**12.48**	**15.12**	**10.95**	**12.71**	**9.41**	**10.29**
KPIs								
Net present value (NPV)	**9.61**	**13.12**	**8.07**	**10.71**	**6.53**	**8.29**	**5.00**	**5.88**
Benefit-to-cost ratio (BCR)	**3.18**	**3.97**	**2.83**	**3.43**	**2.48**	**2.88**	**2.13**	**2.33**
Internal rate of return (IRR)	**152%**	**199%**	**134%**	**170%**	**113%**	**139%**	**90%**	**104%**

Source: Author.

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Glossary

Benefit-to-cost ratio (BCR)	A ratio that measures the efficiency of an investment by comparing the economic benefits (including externalities) to the economic costs associated with a project or initiative over a specified period. It provides a holistic view of the investment's economic viability, considering broader impacts beyond direct financial returns.
West African CFA franc	Official currency of eight West African countries, including Senegal. Issued by the Central Bank of West African States (BCEAO), it is formally called the West African CFA franc. The CFA originally stood for Communauté Financière Africaine (African Financial Community).
Discounting	A financial technique used to adjust the value of future costs or benefits to their present value, reflecting the time value of money. It involves applying a discount rate to future cash flows to determine their current worth, facilitating comparisons and decision making across different time periods. Discounting allows analysts to account for the opportunity cost of capital and the preference for receiving benefits sooner rather than later.
Indicator	Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (UNEP, 2014).
Internal rate of return (IRR)	The discount rate that makes the net present value (NPV) of the economic benefits (including externalities) of a project or initiative equal to zero. It indicates the rate of return at which the project's economic benefits balance its costs, encompassing all economic impacts.
Methodology	The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).
Model validation	The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits	The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.
Net present value	The difference between the present value of the economic benefits (including externalities) and the present value of the economic costs associated with a project or initiative over its lifetime. It quantifies the net monetary impact of the economic aspects of the project, considering all relevant costs and benefits.
Scenarios	Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

1.0 Introduction

1.1 Natur'ELLES Project

This report is part of the Natur'ELLES project, Preservation of Mangrove Ecosystems and Strengthening of Women's Leadership in Natural Resource Management, which aims to improve the conditions of vulnerable communities, particularly women who depend on natural resources in the mangrove ecosystems of the Sine-Saloum Delta and Casamance regions in Senegal. The project works to achieve this by enhancing biodiversity within these ecosystems, promoting more inclusive governance of natural resources, and increasing the benefits derived from conservation efforts. Through nature-based infrastructure and community-led approaches, the project strengthens the vital ecosystem services provided by mangroves, thereby reducing vulnerability and supporting the adaptation of coastal communities to climate change (PMO-NATURELLES).

The Natur'ELLES project is a three-year (March 2023 to March 2026) climate adaptation initiative funded by Global Affairs Canada. It is implemented under the leadership of Socodevi, in collaboration with international partners IUCN, IISD, and Tayo Climate Partners (PMO-NATURELLES).

The project operates in a context where mangrove ecosystems covering approximately 180,000 hectares in the Sine-Saloum and 752,900 hectares in Casamance have lost about 35% of their surface area since the 1980s. This decline is the result of both climate change impacts and human pressures. These ecosystems are recognized as biodiversity hotspots that host 186 plant species, 95 bird species, and numerous threatened species. They provide essential ecosystem services such as coastal protection, carbon sequestration, and support for artisanal fisheries (PMO-NATURELLES).

With a total budget of CAD 20 million from Global Affairs Canada, Natur'ELLES targets 8,000 beneficiaries, including at least 5,600 vulnerable women and young women, across 123 villages within the *Aires du patrimoine communautaire* (APAC),[4] and *Reseau des aires marines protégées* (AMP).[5] The project focuses on three strategic components:

1. enhancing adoption of nature-based infrastructure for mangrove conservation,
2. strengthening inclusive governance of natural resources,
3. increasing economic benefits from ecosystem services for climate-vulnerable communities (PMO-NATURELLES).

The initiative operates through a network of four AMP and five APAC, implementing nature-based infrastructure that combine traditional ecological knowledge with innovative

[4] Indigenous and community conserved areas.
[5] Marine protected areas and Indigenous.

approaches to mangrove restoration, sustainable fisheries management, and women's economic empowerment.

In this context, the International Institute for Sustainable Development (IISD) has applied the Sustainable Asset Valuation (SAVi) methodology to evaluate the ecosystem services provided by the restoration and conservation of mangrove forests in Sine-Saloum. This assessment and report are intended to support evidence-based investment decisions in nature-based infrastructure (PMO-NATURELLES).

1.2 Environmental and Socio-Economic Challenges in the Sine-Saloum Region

The Sine-Saloum Delta, located in west-central Senegal between the city of Joal-Fadiouth to the north and the Atlantic Ocean to the west, is a region of exceptional ecological, cultural, and economic importance. It forms part of the Saloum Delta Biosphere Reserve, a UNESCO-designated site recognized for its rich tropical mangrove ecosystems and biodiversity, which sustain more than 100,000 people (WIACO, 2025). Covering approximately 232,500 hectares, including approximately 58,300 hectares of mangroves, the delta comprises numerous islands, saltwater inlets (*bolongs*), and wetlands that together create a unique estuarine environment (WIACO, 2025).

As an inverse estuary, the region is characterized by the progressive upstream movement of seawater. This phenomenon is mainly linked to high evaporation, limited freshwater inflows, and restricted hydrological circulation. It leads to increased salinity in both water and soils, which weakens local ecosystems and reduces the productivity of agricultural land (WIACO, 2025).

This dynamic intensifies several major environmental pressures, including salinization, coastal erosion, mangrove degradation, and the loss of natural habitats. These impacts directly affect the livelihoods of local communities, particularly agriculture, fishing, the harvesting of forest products, and activities dependent on wetland (WIACO, 2025).

Women in the Sine-Saloum region face several socio-economic vulnerabilities due to their heavy reliance on natural resource-based activities for income generation. Their economic stability is closely linked to fishing and the harvesting of mollusk species—particularly oysters—which provide a critical source of revenue. Beyond aquatic resources, women play a vital role in the valorization of non-timber forest products from mangrove ecosystems, including honey, fruits, medicinal plants, and fuelwood. These activities support local livelihoods and supplement household income. Market gardening represents the primary livelihood for many women, while fishing, oyster harvesting, and mangrove wood collection often serve as alternative income-generating activities during periods of crisis or seasonal economic stress (PMO-NATURELLES).

This SAVi report highlights the significant benefits that mangrove restoration initiatives can deliver for women in the Sine-Saloum region. In addition to contributing to climate change mitigation and biodiversity conservation, these initiatives act as important drivers of social and economic empowerment for women, who are central stakeholders in the sustainable management of mangrove ecosystems.

Given the interconnected ecological and socio-economic challenges facing the Sine-Saloum Delta, integrating ecosystem restoration with community-based sustainable management strategies is essential. Such approaches are critical to protecting mangrove ecosystems, strengthening resilience to climate change, and improving the well-being of populations that depend on these vital natural resources (WIACO, 2025).

1.3 Conservation Framework for Sine-Saloum

The government has taken important steps to address these ecological and socio-economic challenges in the region by developing a network of protected areas, aiming to preserve key ecosystems and support local livelihoods. This area is distinguished by its internationally recognized conservation status, notably the *Parc National du Delta du Saloum*,[6] established in 1976 and spanning 76,000 hectares. In 1981, this same territory was awarded designation as a Biosphere Reserve, covering a broader expanse of 408,906 hectares and reinforcing its ecological significance at both national and global levels (PMO-NATURELLES).

The region also benefits from the establishment of specialized sites such as the *Reseau des aires marines protégées* (AMP),[7] which provides enhanced protection for marine and coastal habitats, and *d'Aires du* patrimoine communautaire (APAC),[8] designed to empower local communities in the stewardship and management of natural resources. Among these is the *Réserve* naturelle communautaire *de Palmarin*,[9] founded in 2001 and comprising 10,480 hectares, which serves as a vital refuge for regional biodiversity and as a model for participatory conservation approaches (PMO-NATURELLES).

Further bolstering this conservation framework, the area includes a RAMSAR site, designated in 1984, acknowledging its importance as a wetland of international significance. The *zone d'importance pour la conservation des oiseaux* (ZICO)[10] highlights critical habitats for avian species, connecting local conservation efforts with global migratory bird networks (PMO-NATURELLES).

The role of community-based governance within the protected area system is receiving increased attention and international support. IUCN is engaged in backing the APAC initiatives, promoting inclusive ecosystem management grounded in the traditions, customary knowledge, spirituality, and socio-cultural practices of local populations. These efforts strive for equitable stewardship and sustained ecological health, recognizing the value of Indigenous perspectives and lived experiences (PMO-NATURELLES).

The importance of APACs was further stressed at the IUCN Congress on Africa's Protected Areas, held in Kigali in July 2022, which reaffirmed the rights of Indigenous Peoples and

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[6] Saloum Delta National Park.
[7] Marine protected areas and Indigenous.
[8] Indigenous and community conserved areas.
[9] Palmarin Community Natural Reserve.
[10] Important Bird Area.

local communities to participate in protected area governance. Despite not yet having formal recognition under existing Senegalese legislation, APACs are gaining prominence as pivotal actors in preserving biodiversity, fostering resilience, and enabling coastal communities to better adapt to the impacts of climate change (PMO-NATURELLES).

Senegal's **National Adaptation Plan for the Coastal Zone** (PNAZC) complements and strengthens the conservation initiatives already established in the Sine-Saloum region. Developed following a national diagnostic process, the PNAZC identifies key adaptation options to enhance the resilience of coastal ecosystems, communities, and infrastructure (MEDD, 2022).

The plan is structured around four strategic pillars: improving coastal protection and land-use planning, strengthening the adaptive capacity of coastal communities, enhancing governance, and improving knowledge and information sharing on climate impacts. Through the promotion of integrated coastal management, the PNAZC provides a coherent framework that aligns national policy with local conservation efforts. Its focus on ecosystem-based solutions, including both hard and soft protection measures, and on participatory governance directly supports the long-term sustainability of the delta's ecosystems. Integrating these national priorities with community-led conservation initiatives in Sine-Saloum will be essential to ensuring that biodiversity protection contributes to greater climate resilience, safeguarding both natural habitats and local livelihoods against increasing climate pressures (MEDD, 2022).

1.4 About This Report

This report constitutes the Sine-Saloum component of a two-part Sustainable Asset Valuation (SAVi) assessment of mangrove restoration in Senegal. The companion report focuses on the Casamance region (see Casamance report). This document focuses specifically on the Sine-Saloum area, examining four protected zones where restoration and conservation interventions are planned:

- **AMP Sokone**: 22 villages, approximately 16,000 residents
- **AMP Bamboung**: 13 villages, 20,398 residents
- **APAC Djilor Djidiack**: one village, 1,053 residents
- **Palmarin Community Natural Reserve**: five villages, 10,400 residents

Across these four sites, the project will reforest 172 hectares of degraded mangroves and conserve 16,900 hectares of existing forest. While roughly 47,851 people live directly within these protected areas, the report also considers potential broader impacts on the Foundiougne and Fatick districts, with populations of 375,388 (CityPopulation, 2023) and 908,858 (ANSD, n.d.) respectively, recognizing that enhanced mangrove ecosystem services benefit coastal communities beyond project boundaries.

To inform policy and investment decisions, this report applies the SAVi methodology to quantify and monetize the full range of benefits and avoided costs from mangrove restoration in Sine-Saloum. The methodology combines systems mapping, local climate projections, spatial landcover analysis, and Excel-based modelling. These approaches culminate in a detailed cost-benefit analysis (CBA) that reports key performance indicators such as the benefit-to-cost ratio, net present value (NPV), and internal rate of return (IRR).

Figure 1. Palmarin site visits

Source: International Institute for Sustainable Development (IISD).

Figure 2. Causal loop diagram workshop

Source: IISD.

The development of this analysis was a collaborative effort involving international and local partners of Natur'ELLES, including Socodevi, IUCN, Tayo, Nebeday, CASADES, CAREM, and REFEPAS, and drew on field data collection by Socodevi. Site visits to RNC Palmarin, APAC Djilor, and the AMPs Sokone and Bamboung provided invaluable firsthand insights into local mangrove conditions, livelihood activities, and governance arrangements. By exploring the restoration sites and speaking directly with reserve managers overseeing conservation zones, the team calibrated the models with on-the-ground realities.

A participatory workshop in Palmarin assembled 24 stakeholders: 17 men and seven women, representing NGOs, academics, community leadership, women's associations, fisheries cooperatives, and farmers. This direct engagement enabled co-creation and validation of the model assumptions while enriching it with stakeholder feedback on seasonal constraints, informal resource governance practices, and emerging threats. The fieldwork captured locally specific dynamics, ensuring the SAVi assessment reflects community priorities including equitable benefit sharing and women's empowerment.

By integrating stakeholder insights with quantitative modelling, the SAVi results demonstrate how mangrove restoration in Sine-Saloum can strengthen coastal resilience, support sustainable livelihoods—especially for women and vulnerable groups—and advance climate adaptation goals across the broader delta system.

This report is structured to provide a cohesive analysis of the potential benefits of mangrove restoration in Sine-Saloum.

It begins by introducing the SAVi methodology, which integrates social, economic, and environmental assessments to evaluate the outcomes of investing in nature-based infrastructure (Section 2). Building on this, the report emphasizes the importance of systems thinking, showing how this approach can be used to capture the interconnectedness of natural, social, and economic systems in Sine-Saloum (Section 2.1).

To demonstrate this concept in practice, a systems map, developed in collaboration with local stakeholders in Sine-Saloum, is presented that highlights key relationships and feedback loops that influence mangrove ecosystems, economic activities, hazard events and health (section 2.2).

This is followed by an analysis of local climate data, including patterns of extreme weather, temperature fluctuations, and precipitation trends, which sets the stage for understanding the region's climate risks (section 2.3).

The report then proceeds with an integrated CBA, detailing the methodology, scenarios, indicators, and results, providing a comprehensive assessment of the NBI impact according to climate change and flood risks scenarios (section 2.4).

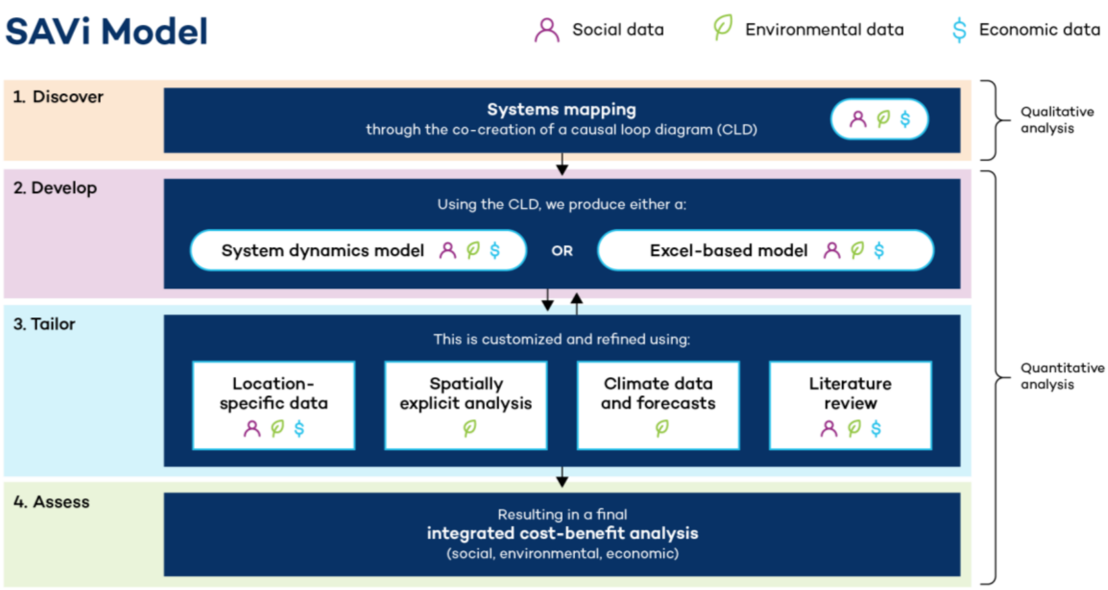
In the conclusion, the key findings are summarized (section 3), with additional detailed results and modelling assumptions provided in the Appendix. Together, these sections form a coherent narrative that builds from theoretical approaches to practical assessments of mangrove restoration in Sine-Saloum.

2.0 Sustainable Asset Valuation

This chapter outlines the methodology and findings of the Sustainable Asset Valuation, as shown in Figure 3. It begins by situating the interventions within a broader context through the use of systems thinking and systems mapping. Building on this qualitative narrative, the chapter incorporates quantitative methods, including climate scenario projections and a comprehensive cost-benefit analysis (CBA), to evaluate the long-term effects of the proposed interventions. This integrated approach facilitates a detailed assessment of both immediate and future outcomes of the mangrove restoration in Sine-Saloum.

SAVi is an assessment methodology that equips policy-makers and investors with a thorough life-cycle analysis of nature-based infrastructure projects. It addresses social, environmental, and economic impacts often neglected in conventional project evaluations. By combining systems thinking with diverse quantitative modelling tools, SAVi captures the full spectrum of costs, including environmental, social, economic, and governance risks. It assigns monetary values to externalities, enabling a refined and holistic evaluation. This comprehensive approach supports investment decisions that align with regional development goals, climate adaptation strategies, and the United Nations Sustainable Development Goals (SDGs), ensuring outcomes that are both financially viable and sustainable.

Figure 3. Sustainable Asset Valuation methodology



Source: IISD.

2.1 Systems Thinking

Systems thinking provides decision-makers with a comprehensive framework that highlights the interconnections among social, environmental, and economic dimensions (Meadows & Wright, 2011; Sanneh, 2018; Stroh, 2015). Instead of concentrating on linear or short-term solutions, it promotes a deeper comprehension of how various elements interact over time, often uncovering both synergies and trade-offs (Sterman, 2000). By focusing on these interrelationships, systems thinking aids in identifying the root causes of issues and ensures that interventions are crafted within the context of long-term strategies (Jackson, 2019). It also clarifies the intricate web of cause-and-effect linkages, making it easier to recognize unintended consequences such as temporary remedies that may escalate problems later (Moallemi et al., 2022). This methodology integrates qualitative understanding with quantitative models, offering both clarity and accuracy for thorough analysis (Probst & Bassi, 2014).

When applied to sustainability, systems thinking broadens the perspective beyond immediate concerns (Voulvoulis et al., 2022). Each choice transforms into more than a momentary decision, becoming instead a catalyst for enduring growth. Maintaining this balance between present needs and future outcomes requires breaking down barriers, connecting different sectors, disciplines, and timescales. Challenges do not exist in isolation, and solutions cannot succeed without collaboration. Systems thinking nurtures this holistic viewpoint, fostering the cross-boundary cooperation essential to addressing today's complex problems (Senge, 2006).

In practical terms, systems thinking serves both as a guide and safeguard for decision-makers. It maps the causal connections between actions and outcomes, revealing feedback loops and behavioural patterns that might otherwise go unnoticed. This broad perspective helps prevent short-sighted measures that could cause greater harm over time, redirecting attention from isolated fixes toward enhancing the system's resilience (Chroust & Finlayson, 2016). Decisions extend beyond addressing immediate issues to establishing frameworks that promote sustainability, equity, and flexibility for the future. Ultimately, systems thinking reminds us that every action is embedded within a larger interconnected web, spanning time and space, empowering decision-makers to craft strategies that address pressing challenges while fortifying the system's adaptive capacity for long-term flourishing.

Applying systems thinking to the Sine-Saloum Delta enables the development of a long-term vision where immediate actions, such as mangrove restoration, are understood as integral components of a broader strategy to restore ecological balance and promote sustainable development. For example, restoring mangroves goes beyond enhancing coastal protection; it also supports resilient ecosystems capable of providing vital services, including regulating water salinity, supporting fisheries reproduction, and sustaining livelihoods for local communities.

The complex dynamics captured in the causal loop diagram highlight how changes in one part of the system can have cascading effects throughout. Population growth and increased demand for wood and agricultural land contribute to mangrove degradation, which in turn reduces fish stock regeneration and aggravates coastal erosion. Furthermore, rising sea levels, decreased freshwater availability, and higher evaporation rates disrupt the delicate balance of water salinity, further stressing mangrove ecosystems and local communities. Recognizing these interconnected challenges, systems thinking emphasizes the need for holistic planning that integrates environmental conservation with social and economic considerations.

2.2 Systems Mapping

One effective way to apply systems thinking is by summarizing the different components and their interactions through a process known as systems mapping. Systems mapping is a collaborative and analytical method used to visualize and understand the elements and interconnections within a complex system. This approach serves various purposes, such as analyzing how a system functions and identifying potential interventions to improve its performance (Barbrook-Johnson & Penn, 2022).

For this SAVi assessment, a systems map, represented through a causal loop diagram (CLD), was created for both the Sine-Saloum and Casamance regions (as illustrated in Figure 4), given the similarity in dynamics for both regions. The CLD examines the key variables within the system, their cause-and-effect relationships, and the feedback loops that drive behaviour. It was developed through an iterative workshop process involving consultations with local communities to capture region-specific dynamics. The process included three field visits to the mangroves and three workshops with local communities. Workshop participants represented diverse groups, including NGOs, representatives from fisheries associations, farmers, women's associations, municipal authorities, academics, and local community leaders. Attendance included 31 participants in Kafountine (25 men and six women), 29 in Baïla (18 men and 11 women), and 24 in Palmarin (17 men and seven women).

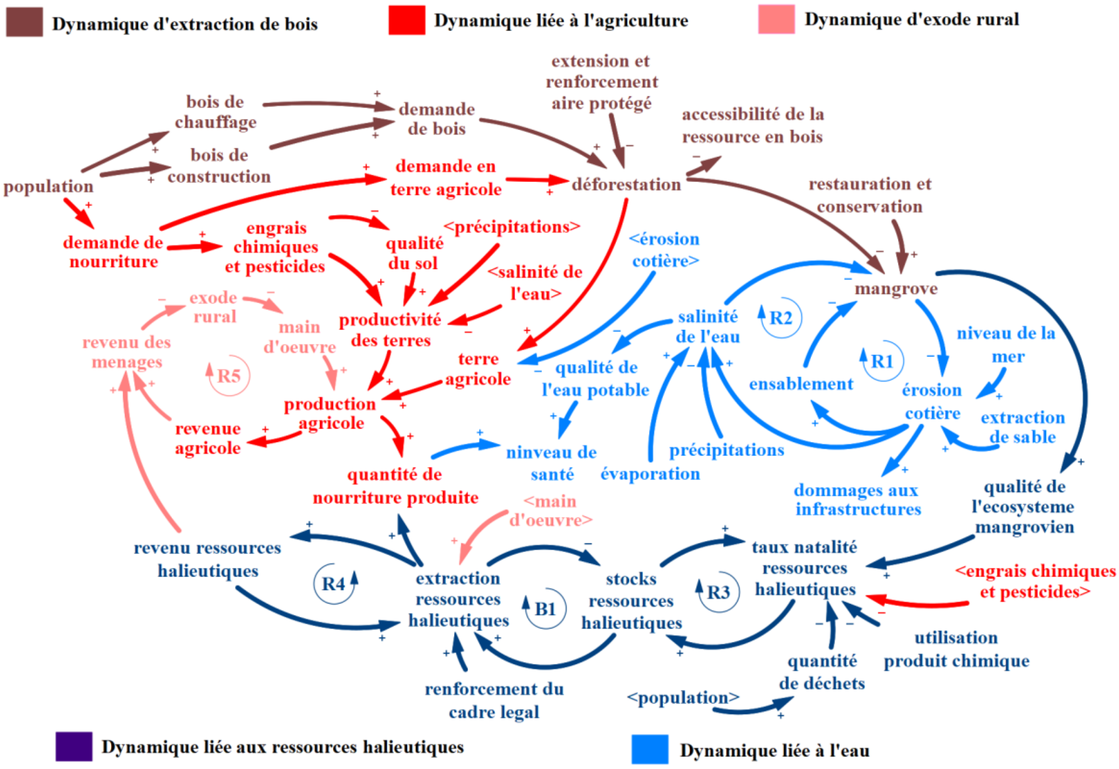
The results comprised a qualitative analysis that gathered local knowledge, validated the causal loop diagram, and identified values and priorities. Additionally, the process identified needs for quantitative analysis, including data, maps, and indicators necessary for the cost-benefit analysis. This participatory and iterative approach ensured that the systems map accurately reflected the complex social-ecological dynamics influencing mangrove conservation and restoration in the regions, forming a solid foundation for the quantitative assessments.

As previously mentioned, the SAVi methodology aims to provide decision-makers with both qualitative and quantitative evidence. The knowledge described here serves as the foundation for the quantitative analysis that follows. In particular, the elements and relationships highlighted through the CLD are closely aligned with the indicators quantified in the integrated cost-benefit analysis. To enhance understanding of the CLD, we recommend referring to the colour coding in the diagram as you follow the narrative.

Box 1. Reading a CLD

A CLD is a tool that supports systems thinking. It shows relationships between the components of a system. Arrows indicate causality and plus and minus signs are used to show the direction of causality. A plus sign means that two variables change in the same direction (a positive correlation), while a negative sign means that they change in opposite directions (a negative correlation). Feedback loops are labelled as either reinforcing (R) or balancing (B). A reinforcing loop indicates that a change in one variable will lead to further change in the same direction, whereas a balancing loop dampens change.

Figure 4. Causal loop diagram of the Casamance and Sine-Saloum regions



Source: Author.

The causal loop diagram (CLD) described in this report aims to represent dynamics within the communities of Casamance and Sine-Saloum. The boundaries of the diagram are defined by the limits of the conservation and restoration projects. It is the result of discussions with various stakeholders in the two regions, including representatives of collectives and associations, village chiefs, and protection agents. The methodology used to develop this diagram follows these steps: (1) drafting of causal links prior to field visits, (2) workshops with focus groups of 5 to 10 participants each, moderated to identify problems, causes, and potential solutions, (3) interviews of moderators by the modeller to establish an overview, (4) adjustments of the CLD by the modeller based on interview outcomes, (5) presentation and validation of the updated CLD with all participants, and (6) final modifications following the presentation.

Causal links are annotated with either a plus (+) or minus (-) sign. A plus sign between element A and element B indicates that an increase in A causes an increase in B, and conversely, a decrease in A causes a decrease in B. A minus sign indicates the opposite: an increase in A causes a decrease in B, and a decrease in A causes an increase in B.

Water-related dynamics: Climate change brings several consequences to the waters and soils of the mangrove ecosystem: (1) decreased rainfall, (2) rising sea levels, and (3) accelerated evaporation. The drop in precipitation disrupts the natural balance between fresh and saltwater in the delta. Normally, a regular flow of freshwater from rainfall and infiltration of saltwater from the sea defines the ecosystem's salinity. This imbalance negatively impacts mangroves and local populations struggling to find freshwater. Rising sea levels cause coastal erosion, with the sea swallowing significant coastal sand stocks and allowing saltwater to penetrate deeper into the delta. This erosion is exacerbated by domestic sand extraction for housing construction. These shifts in sand and sediment and changes in water salinity harm mangroves' ability to survive and regenerate. Lastly, higher temperatures and evapotranspiration also affect water salinity, as shallow mangrove environments lose water through evaporation faster, which increases salinity and compounds negative effects on mangroves. Damage to mangroves reduces coastal retention capacity, amplifying erosion and creating a cycle of ongoing ecosystem degradation.

Fisheries-related dynamics: Mangroves are crucial for the survival of fish stocks because they provide nursery habitats. When mangroves degrade, their capacity to support juvenile fish diminishes, reducing fish reproduction rates. This reduced natural replenishment leads to smaller fish stocks, which in turn limits the resources communities can extract for sustenance and income. Pollution from plastics, fertilizers, and chemicals further cut reproductive rates and stock survival. The level of extraction depends on stock size: larger stocks enable communities to harvest more, generating livelihoods; smaller stocks lead to extraction difficulties. Increased incomes from resource sales can drive further exploitation, often worsened by unregulated overharvesting due to limited enforcement capabilities. Notably, oysters and shellfish are major income sources for women.

Wood extraction dynamics: Population growth increases demand for wood for fuel and construction, directly pressuring mangrove deforestation. As wood resources become scarcer, access becomes more difficult since extraction exceeds natural regeneration. Mangrove wood remains the primary source of energy and construction material for island populations.

Agricultural dynamics: Negative impacts on mangroves are intensified by rising food demand due to population growth. To meet this demand, agricultural lands expand, causing partial deforestation of mangroves and forests for pasture and crop fields. Intensification through fertilizer and pesticide use boosts short-term productivity but degrades soils long-term, leading to yield losses. Soil productivity is also affected by availability of freshwater and salinity levels. During droughts, reduced harvests lead to increased fishing efforts, linking agricultural and fishery dynamics.

Rural exodus dynamics: Household income, primarily from agricultural and fishery product sales, strongly influences quality of life. If incomes stagnate or fail to keep up with living costs, locals increasingly migrate to seek work elsewhere. Educated youth find it difficult to return and engage in local, low-income sectors. This rural exodus reduces labour availability for production activities, correlating strongly with resource depletion and limiting income generation. Moreover, this migration causes loss of ancestral traditions and cultural identity, which are especially important to women.

Restoration and conservation dynamics: Restoration and conservation activities promote a virtuous cycle of natural regeneration: the more mangroves there are, the more seedlings they produce, which leads to further mangrove growth. This benefits communities by enhancing (1) resilience to rising waters and climate events, (2) marine ecosystem quality and water salinity stability, and (3) fish stock reproduction rates. Moreover, expanding and reinforcing protected areas ensures restoration success, maintains natural ecosystem regeneration, and slows or halts conversion of mangrove areas to agriculture or pasture, as well as deforestation from wood demand.

2.3 Climate Data Analysis

Climate data considered in this analysis for Sine-Saloum are based on the Shared Socio-economic Pathways (SSPs) scenarios. The SSPs define different baselines that might unfold according to underlying factors such as population growth, technological innovation, economic development, and resulting greenhouse gas emissions trajectories (Carbon Brief, 2018). Each SSP builds on narrative storylines that capture broad socio-economic trends shaping future societies. Specifically, this study examines three pathways as characterized by Meinshausen et al. (2020):

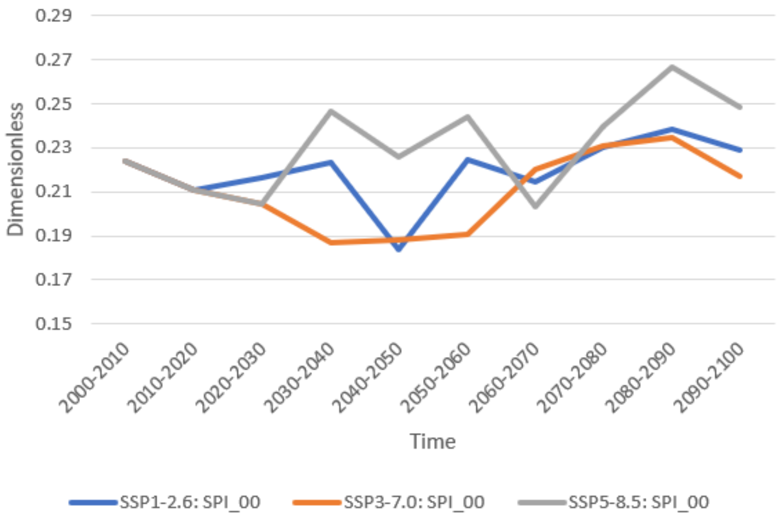
- **SSP1-2.6 (2°C scenario)**: This pathway envisions a world committed to sustainability, featuring low population growth, rapid diffusion of clean energy technologies, and strong international cooperation on climate policy. This scenario assumes substantial investment in renewable energy, restoration efforts, and energy efficiency improvements that together drive down emissions (Meinshausen et al., 2020).
- **SSP3-7.0 (medium-high emissions scenario)**: Characterized by regional rivalry, slow technological progress, and fragmented policy responses. Population growth remains high in developing regions while economic growth and education levels lag, constraining mitigation capacity. Under this scenario, reliance on coal and other fossil fuels persists, and land-use pressures increase, leading to elevated greenhouse gas emissions and warming of approximately 3°C by the end of the century (Meinshausen et al., 2020).
- **SSP5-8.5 (high-fossil-fuel scenario)**: This pathway depicts a world driven by rapid economic expansion, heavy reliance on fossil fuels, and limited climate mitigation. Energy demand soars, met primarily through unabated coal, oil, and gas consumption. Technological advancements focus on productivity and consumption rather than decarbonization, resulting in global temperature increases exceeding 4°C above pre-industrial levels. SSP5-8.5 thus represents a high-emissions future with severe climate impacts and heightened risks to ecosystems and human systems (Meinshausen et al., 2020).

Each SSP presents a distinct trajectory that affects how climate risks, such as extreme wet and dry events, may unfold in Sine-Saloum, guiding the evaluation of future adaptation strategies. While these global scenarios offer valuable insights, it is crucial to recognize that regional impacts can vary significantly. Local factors, such as geography, socio-economic conditions, and environmental characteristics, can modify the way these broad trends are experienced. As a result, while the SSPs provide a useful framework for understanding possible futures, localized climate analysis is vital to capture the unique challenges and risks faced by local communities in Sine-Saloum. With this context in mind, the following sections explore four key climate indicators: extreme dry events, extreme wet events, average temperature, and average monthly precipitation. The data for these indicators come from the European Union's Copernicus database.[11]

Extreme Dry Events

As illustrated in Figure 5, patterns of extreme dryness evolve distinctly across the three emissions scenarios throughout the century. Under SSP1-2.6, the extreme dry percentile remains relatively stable, punctuated by moderate fluctuations but showing only limited increases later in the century. SSP3-7.0 displays a more pronounced dip during the mid-century, with values dropping noticeably between the 2040s and 2060s before recovering toward the end of the period, though still trailing behind the low-emissions scenario. In contrast, SSP5-8.5 exhibits the sharpest fluctuations, with significant peaks emerging after 2070 and persisting through 2100. This climb signals the risk of increasingly severe and frequent dry events if high-emissions pathways continue. Such a trajectory could amplify drought-related impacts in the region, undermining ecosystem stability, threatening water availability, and exposing communities to both greater vulnerability and resource insecurity.

Figure 5. Extreme dry percentile



Source: EU Copernicus data.

Extreme Wet Events

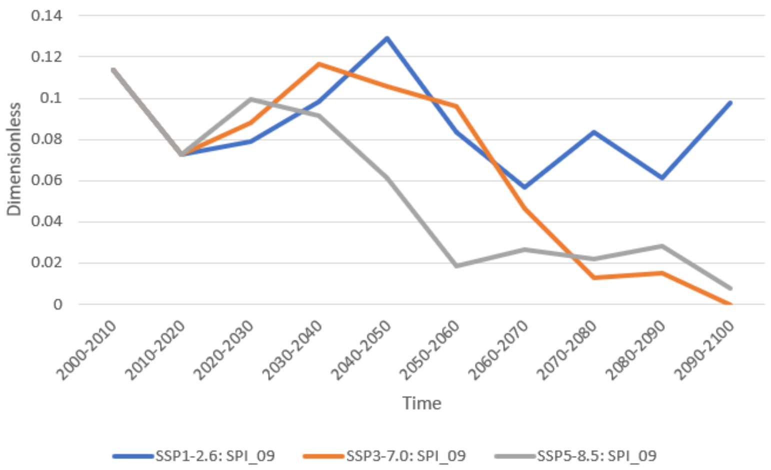
Extreme wet event patterns diverge significantly across emission scenarios throughout the century (Figure 6). Under the high-emissions scenario (SSP5-8.5), extreme wet percentiles begin relatively high early in the century but decline sharply, approaching near-zero by 2070 and remaining suppressed through 2100. The medium-high emissions pathway (SSP3-7.0) demonstrates initial growth through the 2030s to 2040s, reaching a peak, then undergoes rapid decline with extreme wet events becoming increasingly rare in the latter half of the century.

[11] Available at https://www.copernicus.eu/en.

In contrast, the low-emissions scenario (SSP1-2.6) exhibits a more resilient pattern. Following a peak around 2040 to 2050, extreme wet percentiles stabilize in the second half of the century, with a notable upturn near 2100 suggesting recovery and sustained capacity for intense precipitation events.

The declining extreme wet percentiles under higher-emissions scenarios indicate fewer intense precipitation events despite overall wetter trajectories, reflecting a critical shift in precipitation distribution and intensity. This reduction carries significant hydrological implications: decreased precipitation intensity may limit groundwater recharge and reduce river flows, fundamentally altering regional hydrology and compromising water security for both people and ecosystems.

Figure 6. Extreme wet percentile



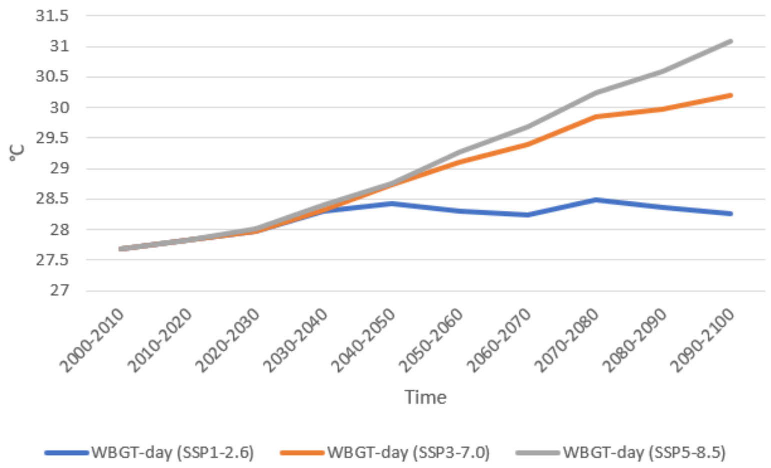
Source: EU Copernicus data.

Average Monthly Temperature

As shown in Figure 7, temperature projections reveal markedly different trajectories across the three emissions scenarios. Under the low-emissions scenario (SSP1-2.6), average monthly temperatures rise modestly from approximately 27.8°C to about 28°C by 2080, then stabilize and even decline slightly toward the end of the century. This pattern reflects successful climate mitigation efforts that limit warming and achieve temperature stabilization. The medium-emissions pathway (SSP3-7.0) demonstrates a steady upward trajectory throughout the century, reaching approximately 31°C by 2100. In stark contrast, the high-emissions scenario (SSP5-8.5) exhibits the most pronounced warming trend, with temperatures climbing continuously to exceed 31°C by century's end.

This escalating temperature trend under higher emissions scenarios poses significant threats to the region's ecosystems and communities. Increased temperatures accelerate evapotranspiration rates, intensify water stress, and can disrupt the delicate salinity balance critical to mangrove health. As temperatures rise, the capacity of soils to retain moisture diminishes, exacerbating drought conditions and potentially triggering the cascading effects outlined in the systems map. Higher temperatures also stress fisheries, reduce agricultural productivity, and threaten the livelihoods of communities dependent on natural resources.

Figure 7. Average monthly temperature



Source: EU Copernicus data.

Average Precipitation

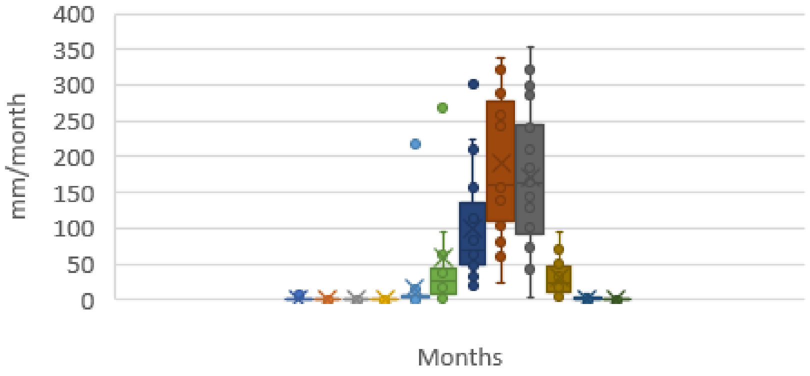
Figure 8 shows in a box plot the average precipitation (mm/month) in the study area for the period 2000 to 2020 under the SSP5-8.5 scenario, while Figure 9 shows the same variables but for the period from 2040 to 2060.

The period from 2000 to 2020 demonstrates a distinct wet season concentrated between June and October, with peak rainfall occurring around August to September, reaching approximately 300mm per month. During this period, the dry season extends from November through May, with minimal precipitation rarely exceeding 50mm per month.

Looking toward the mid-century projection (2040 to 2060), the seasonal distribution maintains its general pattern but shows shifts in intensity and variability. While the wet season timing remains similar, there appears to be increased variability in precipitation amounts. The dry season continues to dominate much of the year, but the uncertainty ranges suggest greater unpredictability in both timing and magnitude of rainfall events.

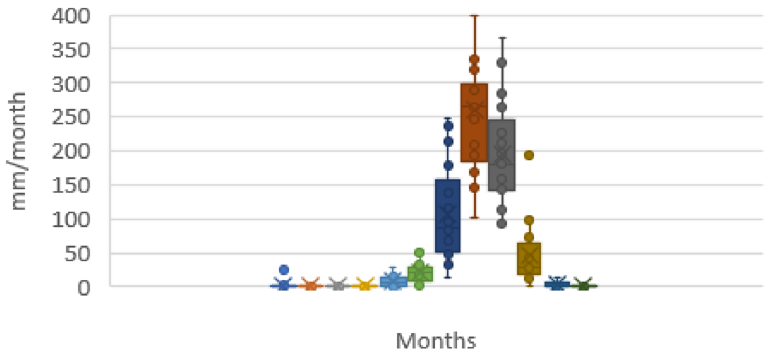
These precipitation changes have implications for the region's social-ecological systems as described in the causal loop diagram. Shifts in seasonal timing or intensity can disrupt agricultural cycles, affect freshwater availability for communities, and alter the delicate salinity balance crucial for mangrove ecosystems. Increased variability may exacerbate the challenges faced by women and vulnerable communities who depend on predictable seasonal patterns for fishing, agriculture, and resource collection.

Figure 8. Average precipitation (2000 to 2020)



Source: EU Copernicus data.

Figure 9. Average precipitation (2040 to 2060)



Source: EU Copernicus data.

As dry periods lengthen under future climate scenarios, soils will increasingly compact and become more water repellent, further reducing infiltration. When intense precipitation finally occurs, whether through heavier seasonal rains or more frequent extreme wet events, the runoff generated on these hardened soils can overwhelm natural drainage pathways. This combination of extended drought and abrupt increases in rainfall heightens the risk of flooding, eroding riverbanks and inundating low-lying areas.

In the cost-benefit analysis, we will examine how variations in extreme weather patterns across SSP scenarios translate into infrastructure damage costs and economic risks. By analyzing the frequency and intensity of flood events and SSP pathways (extreme wet events) over the project lifecycle, we can quantify potential impacts on critical infrastructure and assess the economic value of mangrove restoration. This approach allows us to estimate avoided costs from flooding, coastal protection benefits, and enhanced resilience, thereby capturing the full range of protective services that restored mangrove ecosystems provide under different climate futures. By exploring how key metrics such as benefit-cost ratio (BCR), net present value (NPV), and internal rate of return (IRR) evolve under these different scenarios, we gain deeper insights into the potential economic implications of flood risks.

2.4 Integrated CBA

The following section presents an integrated cost-benefit analysis (CBA) aimed at evaluating the economic viability of mangrove restoration under various flood and SSP scenarios. This analysis is divided into three key subsections.

- First, the methodology subsection outlines the approach and key assumptions used to assess the costs and benefits, providing a clear understanding of how the results were derived.
- Second, the indicator subsection goes through the definition of all indicators present in the CBA. This allows the reader to better grasp the true meaning of the elements quantified.
- Finally, the CBA results subsection presents the monetized outcomes, comparing the costs and benefits across the different flood risks and climate scenarios. Through this analysis, we aim to provide insights into the long-term economic implications of adopting NBI strategies versus maintaining the status quo.

2.4.1 Methodology

The cost-benefit analysis employs an Excel-based input-output model spanning 27 years (2024 to 2050). The model begins by defining and projecting key parameters annually, including asset exposure, costs, and ecosystem service values. These inputs are evaluated across two scenarios: a business-as-usual (baseline) scenario representing current conditions, and a nature-based infrastructure (NBI) scenario representing mangrove restoration outcomes. (See Appendix B for complete modelling assumptions and parameter specifications.)

For each scenario, the model computes annual values of key indicators. For instance, for determining flood damage costs, baseline values are calculated to reflect current conditions, whereas under an NBI scenario they account for enhanced coastal protection from mangrove restoration. By subtracting baseline values from NBI values, the model quantifies avoided costs, thereby capturing the direct benefits of the intervention. The results presented in this report represent the difference between the baseline scenario and the NBI scenario.

To explore how climate change and flood frequencies affect outcomes, the NBI scenario is evaluated across two climate trajectories, SSP3-7.0 (medium-high emissions) and SSP5-8.5 (high emissions), and two distinct flood regimes. Under the severe flood regime, extreme flood events are assumed to recur every two years. Under the moderate flood regime, extreme flood events are assumed to recur every five years. (See Appendix A for the methodology on flood regimes assumptions.)

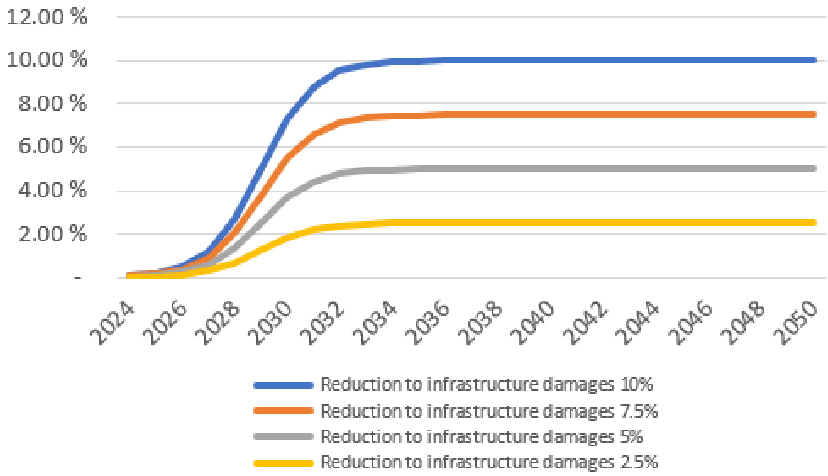
Each of the resulting four scenario combinations is further examined under four levels of assumed infrastructure damage reduction, 2.5%, 5%, 7.5%, and 10%, reflecting uncertainty in the protective performance of restored mangroves (Figure 10). These percentages correspond to the proportional reduction in flood-related damage costs that the project can avert: the 2.5% threshold models a conservative, minimal protection case, while the 10%

threshold represents an optimistic upper bound on mangrove efficiency protection. This approach accounts for uncertainty in restoration success and provides decision-makers with a better understanding of how restoration performance influences overall project viability (Table 1).

These scenarios are used to explore different possible levels of effectiveness because the actual impact of mangroves on infrastructure protection remains uncertain. In practice, their exact level of effectiveness cannot be known in advance. Rather than assuming a single value, several levels of effectiveness are therefore tested to account for this uncertainty.

This makes it possible to assess how results change depending on mangrove performance. For example, what happens if they are only slightly effective, moderately effective, or highly effective? This provides a range of possible results rather than a single estimate.

Figure 10. Protection efficiency from 2.5% to 10% reduction to infrastructure damage[12]



Source: Author.

[12] This graph shows how the effectiveness of mangroves in protecting infrastructure evolves over time, based on different assumptions. At the beginning, between 2024 and 2026, mangroves provide almost no measurable protection. From 2027 onward, their effect begins to appear, then increases rapidly between 2028 and 2031. This corresponds to the period when the mangroves become sufficiently developed to reduce damage. Then, from the early 2030s onward, their effectiveness stabilizes, meaning that their protective capacity remains in place. For example, one scenario assumes that mangroves reduce damage by 7.5%. In this case, protection gradually increases from the late 2020s, reaches its maximum level in the early 2030s, and then remains stable. This scenario represents one possibility among others, depending on the actual level of mangrove effectiveness observed in the field. The graph therefore illustrates different possible trajectories and shows that mangroves can become an important and sustainable way to protect infrastructure once they are sufficiently developed.

Table 1. Reduction to infrastructure damage due to protection efficiency of the mangroves restoration project

Protection efficiency	Reduction in infrastructure damage
High	10%
Medium/high	7.5%
Medium/low	5%
Low	2.5%

Source: Author.

Together, these metrics allow the model to simulate flood risk under different severity assumptions by specifying both the likelihood of extreme floods and the practical frequency at which they might occur.

The model aggregates annual costs and benefits across the entire project timeline to calculate total costs and total benefits. The net present value (NPV) then converts all future cost and benefit flows into equivalent present-day monetary values, determining whether the project generates net social, environmental, and economic value. A positive NPV indicates project viability; a negative NPV signals that costs exceed benefits and the project should not proceed. To provide a comprehensive economic assessment, the model also calculates the benefit-cost ratio (BCR), which measures benefits relative to costs, and the internal rate of return (IRR), which indicates the implicit annual return on investment.

All future cash flows are discounted to present value using a 3.5% annual social discount rate, consistent with the United Kingdom's Green Book guidance on public sector appraisal (HM Treasury, 2020). This discount rate reflects the opportunity cost of capital and ensures that benefits and costs occurring in different time periods are comparable on equivalent terms.

This narrative approach, together with sensitivity testing across SSP climate scenarios, flood frequency, and varying levels of infrastructure damage reduction, provides a clear framework for understanding how mangrove restoration generates economic value through avoided flood damage and enhanced resilience.

2.4.2 Indicators

To evaluate the costs and benefits of the baseline and the NBI scenario, a range of indicators were identified through the systems mapping process to capture the direct and indirect impacts of the interventions. These indicators provide a comprehensive picture of the economic, social, and environmental implications of the scenarios. Each indicator measures a specific aspect of the mangrove's ecosystem and infrastructure performance, allowing for a nuanced understanding of the restoration project. Below is a brief definition of each indicator used in the CBA:

Table 2. List and definitions of CBA indicators

Direct costs	
Implementation costs (CAPEX)	The initial costs associated with carrying out the mangrove restoration in AMP Sokone, AMP Bamboung, APAC Djilor Djidiack, Palmarin Community Natural Reserve.
Maintenance costs (OPEX)	Ongoing costs required to conserve mangroves over time, such as community stewardship via patrols and sustainable-harvest, bank-stabilization structures to control erosion, ongoing field records, and annual technical reviews.
Avoided costs/loss	
Avoided damage to infrastructure	Savings resulting from reduced damage to residential buildings, public buildings, and roads due to flood mitigation measures provided by the NBI.
Avoided health-related costs	Reduction in health care expenditures from fewer respiratory illnesses attributable to mangrove restoration.
Added benefits	
Fishery revenue	Benefits from preserving fish nurseries and biodiversity within the mangrove restoration, as healthy ecosystems contribute to the sustainability of fisheries.
Agricultural revenue	Benefit from enriching soil fertility through the buildup of organic material and improving water availability via enhanced groundwater recharge, leading to more productive and resilient crop yields. Agricultural production includes rice, maize, millet, sorghum, and watermelon.
Seafood harvest revenues	Enhanced seafood harvest through the restoration of mangrove nursery habitats that support fish, crustaceans, and mollusks; improved water quality from natural filtration of sediments and pollutants; and increased coastal ecosystem productivity leading to higher and more sustainable fishing yields.
Drinking water supply	Improved drinking water supply by filtering sediments and contaminants, stabilizing coastal aquifers through enhanced groundwater recharge, and protecting watershed integrity, ensuring cleaner, more reliable freshwater sources.
Food supply	Additional food produced by mangrove-supported systems that is retained for household consumption and community redistribution rather than sold in markets.
Wood supply	Increased wood supply by expanding forest area enabling sustainable harvesting of fuelwood and construction materials through managed regrowth cycles and community stewardship.
Job creation	New jobs generated through the implementation of the mangrove restoration project.
Carbon sequestration	The social cost value assigned to carbon dioxide captured and stored by restored ecosystems, contributing to climate change mitigation.

Source: Author.

2.4.3 Results

This subsection begins by presenting the cumulative results of the integrated CBA for each combination of SSP climate pathway and flood regime, thereby capturing the full range of flood-frequency scenarios from 2024 through 2050. All monetary figures are expressed in present-value terms, discounted at 3.5% as described in the Methodology section. First, we compare NBI outcomes across different climate and flood frequency scenarios, evaluating performance through key performance indicators (KPIs) including the benefit-cost ratio (BCR) and net present value (NPV). This comparison examines how avoided infrastructure damage costs influence NBI performance variations, determining the added value generated for communities and their resilience. Second, we analyze the broader composition of benefits and avoided costs beyond infrastructure protection, assessing the project's comprehensive impact across multiple benefit categories. Finally, we conduct a targeted analysis of gender-differentiated outcomes, examining the specific benefits and avoided costs generated for women and quantifying the added value created for female community members.

We evaluate the NBI's overall performance using net present value (NPV) and the benefit-cost ratio (BCR). Variation in these indicators across climate and flood-frequency scenarios reflects differences in avoided infrastructure damage costs. Since all other benefits—health savings and ecosystem-service revenues—remain constant across scenarios, NPV and BCR fluctuate in direct proportion to the flood damage prevented by restored mangroves under each scenario. This sensitivity reveals how climate intensity and flood frequency fundamentally influence the business case for nature-based infrastructure.

Table 3 summarizes the CBA results for the four levels of protection efficiency (infrastructure damage reduction due to floods at 10%, 7.5%, 5%, and 2.5%) under two flood frequency regimes: moderate (floods every five years) and severe (floods every two years). The analysis reveals a clear upward trend in NPV as protection efficacy increases. At the lowest efficiency (2.5%), the moderate regime yields an NPV of approximately XOF 5.4 billion, whereas improving efficiency to 10% under the same regime boosts NPV to over XOF 23 billion. Even under the severe flood regime, increasing mangrove protection efficiency from 2.5% to 10% more than doubles NPV, demonstrating that higher levels of ecosystem protection generate substantially greater economic value through flood damage avoidance. Total project costs are estimated at XOF 4.41 billion (discounted at 3.5%).

The BCR reinforces these findings, demonstrating consistent societal profitability across all scenarios. At the most conservative level, with moderate flood frequency and only 2.5% damage reduction efficiency, the BCR reaches 2.2, indicating that every XOF invested in mangrove restoration generates XOF 2.2 in returns. This ratio climbs substantially under the other scenarios, peaking at XOF 6.2 for severe flood scenarios with high protection efficiency (10% damage reduction). This high-return scenario means that each XOF invested yields XOF 6.2 in benefits, underscoring strong economic returns that mangrove restoration can deliver effectively in high-risk flood environments.

In addition, project performance consistently improves under scenarios characterized by higher flood frequency. This pattern holds true regardless of the assumed level of damage reduction, indicating that the benefits of mangrove restoration become increasingly valuable as flood events become more frequent. In other words, even if infrastructure damage is only moderately reduced, the cumulative avoided costs rise substantially when floods occur more often, further enhancing the economic viability and resilience outcomes of the project.

Table 4 evaluates the economic performance of mangrove restoration under two SSP climate pathways. As observed in the climate analysis, the high-emissions SSP5-8.5 pathway intensifies flood risks sharply after the end of the century, while the lower-emissions SSP3-7.0 pathway produces more frequent flooding earlier on. Despite SSP5-8.5 being considered as severe, its major flood events are less common before the end of the century, delaying much of the avoided damage until later years. In contrast, SSP3-7.0 drives more regular floods throughout the 2024 to 2050 period, so restoration delivers immediate, cumulative avoided damage.

As a result, NPVs under SSP3-7.0 exceed those under SSP5-8.5 at every protection efficiency level. For instance, at 10% reduction in infrastructure damage, the project yields an NPV of XOF 17.5 billion under SSP3-7.0, nearly double the XOF 9.4 billion achieved under SSP5-8.5. Even under the lowest protection efficiency (2.5%) and the high-emissions SSP5-8.5 scenario, the project still delivers a positive net present value of XOF 5 billion.

This outcome underscores that mangrove restoration generates the greatest economic returns when it mitigates frequent, high-intensity flood events, highlighting its critical role in protecting communities against extreme climate impacts.

Under the SSP5-8.5 pathway, the benefit-cost ratio at low efficiency (2.5% infrastructure damage reduction) stands at XOF 2.13. This indicates that each XOF invested in mangrove restoration returns just over twice its cost, even at low efficiency protection. By contrast, under the SSP3-7.0 pathway, with its higher flood frequency before 2050, the BCR rises to 3.97 at 10% protection efficiency level. In practical terms, this means that for every XOF spent, communities gain nearly four XOF in avoided damage and benefits in a high protection efficiency scenario.

These results confirm that investing in mangrove restoration projects in Sine-Saloum yields robust economic performance. The clear linkage between higher protection efficiency, flood frequency, and increased returns underscores the value of targeting restoration in vulnerable flood-prone zones.

Table 3. Summary table of integrated cost-benefit analysis based on flood frequency scenarios, figures in millions XOF, discounted at 3.5%

Reduction in damage to infrastructure	Reduction in damage, 10%		Reduction in damage, 7.5%		Reduction in damage, 5%		Reduction in damage, 2.5%	
Flood frequency	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**
Direct costs								
Construction costs	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Operational and maintenance costs	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37
Total costs	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**
Avoided costs								
Avoided damage to infrastructure	7.98	19.63	5.98	14.72	3.99	9.82	1.99	4.91
Avoided health-related costs	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Added benefits								
Fishery revenue	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Agricultural revenue	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Seafood harvest revenues	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Drinking water supply	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Food supply	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Wood supply	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Job creation	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Carbon sequestration	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84

Reduction in damage to infrastructure	**Reduction in damage, 10%**		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
Total benefits and avoided costs	**15.86**	**27.51**	**13.86**	**22.60**	**11.87**	**17.69**	**9.87**	**12.78**
KPIs								
Net present value (NPV)	**11.44**	**23.09**	**9.45**	**18.19**	**7.45**	**13.28**	**5.46**	**8.37**
Benefit-to-cost ratio (BCR)	**3.59**	**6.23**	**3.14**	**5.12**	**2.69**	**4.01**	**2.24**	**2.90**
Internal rate of return (IRR)	**150%**	**303%**	**135%**	**254%**	**118%**	**201%**	**95%**	**14%**

Source: Author.

Table 4. Summary table of integrated cost-benefit analysis based on SSP scenarios, figures in millions XOF, discounted at 3.5%

	Reduction in damage, 10%		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
SSP scenario	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**
Direct costs								
Construction costs	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Operational and maintenance costs	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37
Total costs	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**	**4.41**
Avoided costs								
Avoided damage to infrastructure	6.14	9.66	4.61	7.24	3.07	4.83	1.54	2.41
Avoided health-related costs	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Added benefits								

	Reduction in damage, 10%		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
Fishery revenue	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Agricultural revenue	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Seafood harvest revenues	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Drinking water supply	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Food supply	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Wood supply	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Job creation	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Carbon sequestration	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total benefits and avoided costs	**14.02**	**17.53**	**12.48**	**15.12**	**10.95**	**12.71**	**9.41**	**10.29**
KPIs								
Net present value (NPV)	**9.61**	**13.12**	**8.07**	**10.71**	**6.53**	**8.29**	**5.00**	**5.88**
Benefit-to-cost ratio (BCR)	**3.18**	**3.97**	**2.83**	**3.43**	**2.48**	**2.88**	**2.13**	**2.33**
Internal rate of return (IRR)	**152%**	**199%**	**134%**	**170%**	**113%**	**139%**	**90%**	**104%**

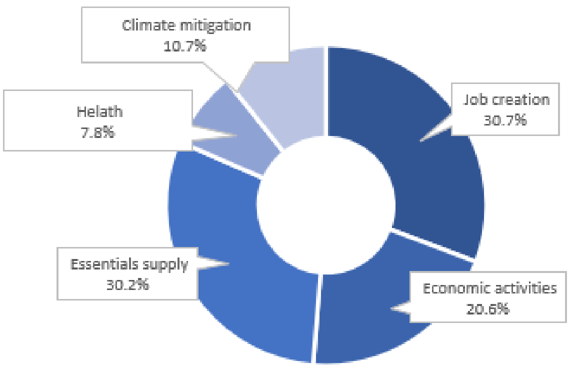
Source: Author.

Beyond preventing infrastructure damage, mangrove restoration generates a diverse array of benefits that strengthen the resilience and prosperity of coastal communities. The nine identified benefits and avoided costs can be categorized in five main impacts (Figure 11).

- First, job creation from planting accounts for 31% of total non-infrastructure benefits.
- Second, essential supplies—comprising seasonal food production, sustainably harvested wood, and improved drinking-water filtration—together represent 30%.
- Third, economic activities, including additional agricultural revenues, enhanced seafood harvests, and increased fishery revenue contribute 20.6%, underscoring improved local markets for crops and marine products.
- Climate mitigation through carbon sequestration delivers 10.7% of the benefits, highlighting the project's role in offsetting CO_2 emissions.
- Finally, improved health and well-being, driven by pollutant filtration and reduced disease incidence contribute 7.8%.

The fact that job creation and essential supply each comprise roughly one-third of the benefits emphasizes that livelihood support and resource provisioning are the primary impacts of mangrove restoration, while economic gains, climate mitigation, and health improvements further reinforce the value of the NBI.

Figure 11. Distribution of benefits (excluding avoided costs to infrastructure damage)



Source: Author.

A detailed examination of benefits and avoided costs reveals the following impacts:

Job creation is a major outcome, with restoration activities yielding XOF 2.42 billion. Local communities lead planting, monitoring, and maintenance tasks, thereby acquiring practical skills in nursery management and restoration. This engagement can foster shared stewardship and strengthens social cohesion within communities.

Economic activities show a combined boost of XOF 1.62 billion, drawn from revitalized fisheries (XOF 90 million), enhanced agricultural production (XOF 1.24 million), and increased seafood harvesting (XOF 290 million). Soil enrichment and improved groundwater recharge support more reliable crop yields, stabilizing household incomes. Expanded mangrove nursery habitats simultaneously increase juvenile fish survival, directly benefitting artisanal fishers. By integrating land- and sea-based value chains, restored mangroves empower local cooperatives to process and market surplus agricultural and fishery products, positioning these ecosystems as engines of sustainable economic growth.

The **supply of essential resources** is significantly enhanced, delivering a total value of XOF 2.38 billion. Households secure XOF 1.36 billion worth of food for direct consumption, reducing reliance on markets. Sustainable wood harvesting contributes XOF 1 billion for fuel and construction, while improvements to water quality yield XOF 20 million in safer drinking water. By reducing the daily time burden of resource collection, these gains free up opportunities for education and other income-generating activities.

Mangroves act as natural air filters, trapping atmospheric particulates and improving air quality. This service leads to a reduction in respiratory diseases, which in turn decreases clinic visits and medical expenses. Healthier populations also maintain higher productivity and school attendance, reinforcing community resilience and yielding significant health care savings of XOF 610 million in avoided health-related costs.

Finally, mangrove restoration contributes to climate mitigation and carbon finance. Carbon sequestration is valued at XOF 850 million, creating opportunities within voluntary carbon markets. (For additional information, see guidance document on financial instruments for mangrove restoration projects.)

Benefits and Avoided Costs for Women: Gender-based analysis

Women in Senegal depend heavily on mangrove ecosystems for their livelihoods yet face disproportionate risks and constraints. As primary harvesters of shellfish, particularly oysters, women derive a significant share of their income from mangrove resources (PMO-NATURELLES). Despite mangroves providing ecosystem goods and services, their decline in Senegal by nearly half since the 1980s undermines women's economic security and exacerbates poverty (PMO-NATURELLES). Conservation measures, including restrictions on natural resource use in protected areas, often limit women's access to critical resources and exclude them from decision-making processes that regulate harvesting rights and local development (PMO-NATURELLES).

Women's adaptive capacity is also constrained by limited access to technical knowledge, equipment, and financial capital, combined with underrepresentation in governance structures. These factors significantly hamper their ability to respond effectively to climate-related shocks. Therefore, addressing these gender vulnerabilities is essential. By empowering women through inclusive governance of nature-based infrastructure, communities can simultaneously enhance ecosystem conservation and strengthen women's resilience to climate change (PMO-NATURELLES).

The gender-based analysis demonstrates that women accrue XOF 1.35 billion in direct project benefits, approximately 29% of the XOF 4.65 billion[13] total value generated by the project (See Appendix A – CBA). These benefits arise from four impact categories: enhanced agricultural revenues, expanded opportunities in fisheries and seafood harvesting, job creation, and reductions in health-related expenses. Together, these gender-differentiated benefits and avoided costs underscore the critical role women play in, and the tangible gains they derive from, NBI interventions (Table 5).

Agriculture: Rural women constitute nearly 70% of Senegal's agricultural workforce and are responsible for producing approximately 80% of the national food supply, underscoring their indispensable role in the country's food security and rural economy. Although they provide the majority of labour, women are frequently marginalized in farm decision making regarding crop choices, resource allocation, and production methods (Alliance of Bioversity International & CIAT, 2024). In the context of mangrove restoration in Sine-Saloum, agricultural revenue emerges as the primary benefit for women, accounting for 63% of total gender differentiated benefits, equivalent to an added value of XOF 850 million. This demonstrates that NBI can generate additional income-earning opportunities for women.

Fishery and seafood harvesting: Artisanal fishing represents a critical economic activity for women in Senegal. Throughout the fishery value chain, women perform essential roles: they smoke, salt, and clean fish; organize product transport; and negotiate sales in local and regional markets. Yet despite these indispensable contributions, women's full participation is constrained by socio-economic barriers, limited access to capital and fishing infrastructure—and in some communities—by religious and cultural norms that restrict mobility and decision-making authority (OceanRisk 2023).

Seafood harvest revenues constitute the second-largest benefit category, valued at XOF 290 million (21.5% of total benefits), demonstrating significant value creation in marine resource activities traditionally managed by women. These include shellfish gathering, oyster harvesting, and small-scale aquaculture processing, activities where women exercise considerable autonomy and technical expertise. Restoring mangrove nursery habitats directly enhances these fishery-based livelihoods, expanding income-generating opportunities while strengthening women's economic security.

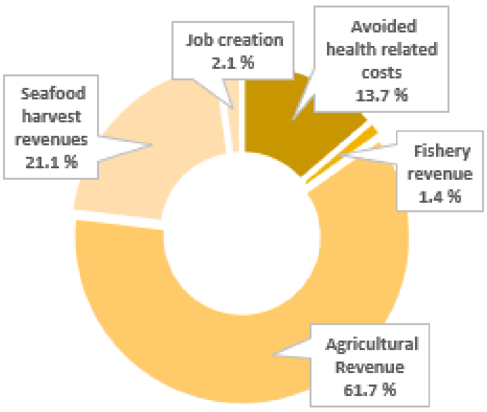
In contrast, artisanal fishery activities generate an added value of XOF 20 million (1.5% of total), reflecting women's limited direct participation in formal fishing operations compared to their dominant roles in seafood processing and harvesting. While this represents a smaller added value for women, it remains quite relevant as it provides additional income diversification opportunities and demonstrates their broader engagement across the marine value chain.

[13] Value based on the same avoided costs and benefits: avoided health-related costs, fishery revenue, agricultural revenue, and seafood harvest revenues.

Health care: Climate change significantly exacerbates health care costs for women in Senegal by compounding existing barriers to health care access and increasing the financial burden on households. Women in underserved regions must travel between 23 to 75 kilometretres to reach the nearest health facility, a journey made increasingly difficult and expensive due to flooding during rainy seasons and other climate hazards that damage roads and transportation infrastructure (International Budget Partnership, n.d.). The project is expected to generate significant avoided cost by reducing health care costs through pollution mitigation provided by mangroves. This analysis focuses exclusively on the role of mangrove forests in filtering airborne pollutants, thereby lowering the incidence of respiratory illnesses and the associated treatment expenses. These avoided health-related costs amount to XOF 190 million (13.7% of total benefits), representing substantial preventive health gains that ease financial burdens on women.

Job creation: Mangrove restoration activities create significant employment for women in coastal communities. By engaging women in seedling cultivation, planting, and restored area maintenance, the project generates approximately XOF 30 million in direct earnings. This boosts household income while building local capacity in restoration techniques and ecosystem stewardship. Women's participation in these roles fosters community ownership of mangrove restoration, ensures higher survival rates through regular monitoring, and promotes gender-inclusive economic empowerment that extends beyond restoration to broader livelihood security.

Figure 12. Composition of added benefits and avoided costs for women



Source: Author.

Table 5. Composition of added benefits and avoided costs for women, figures in billion XOF

Benefits for women	CFA
Avoided health-related costs	0.19
Fishery revenue	0.02
Agricultural revenue	0.85
Seafood harvest revenues	0.29
Job creation	0.03
Total	**1.38**

Source: Author.

To conclude, the gender-based analysis underscores that women derive substantial socio-economic gains from mangrove restoration yet continue to face significant barriers. Although they capture XOF 1.38 billion, about 29% of total value for the same benefits, women's income security remains jeopardized by ecosystem decline, restricted resource access, and exclusion from governance. Strengthening women's participation in community management bodies and lowering technical and financial barriers will not only safeguard mangrove ecosystems but also amplify women's resilience and livelihood opportunities under climate stress.

3.0 Conclusions

The mangrove restoration project delivers strong economic returns across all scenarios, with benefit-cost ratios exceeding 2:1, even under conservative assumptions. The value of restoration increases with flood risk intensity, as higher protection efficiency and more frequent flood events significantly enhance project performance.

Beyond flood protection, mangrove restoration generates a wide range of additional benefits and avoided costs. These include job creation, improved health outcomes, supply of essential resources, carbon sequestration, and expanded economic activities, all contributing value beyond avoided infrastructure damage.

This diversity of benefits makes nature-based infrastructure projects especially valuable for coastal communities facing climate change. They protect infrastructure, strengthen livelihoods, and promote long-term environmental sustainability.

Implementing mangrove restoration in the coastal zones of Sine-Saloum presents a strong economic case. Total project costs are estimated at XOF 4.41 billion (discounted at 3.5%), while the net present value (NPV) ranges from XOF 5.46 billion to XOF 23.09 billion across different flood-frequency and infrastructure damage reduction scenarios. The benefit-cost ratios (BCRs) range from 2.2 to 6.23, meaning that every XOF invested yields between XOF 2.2 and XOF 6.2 in avoided damage and benefits.

Under varying climate emission pathways, mangrove restoration performs well across all SSP scenarios and protection efficiency levels. In the SSP5 8.5 pathway, a 2.5% protection efficiency produces an NPV of XOF 5.0 billion, increasing to XOF 13.13 billion under SSP3 7.0 with a 10% efficiency rate. The BCR follows a similar trend, rising from 2.13 under low efficiency in SSP5 8.5 to 3.97 under high efficiency in SSP3 7.0. These results show that greater flood frequency and stronger protection efficiency directly enhance project performance.

Beyond flood protection, the project generates significant benefits: job creation (30.7%), essential resource provisioning (30.1%), improved agricultural and fisheries revenue (20.6%), carbon sequestration (10.7%), and health savings (7.8%). This diverse portfolio of benefits highlights the value of nature-based infrastructure in supporting sustainable livelihoods, strengthening community resilience, and contributing to climate change mitigation.

Empowering women in mangrove restoration initiatives is essential to maximizing project benefits and ensuring long-term sustainability. Although women capture a significant share of benefits, estimated at XOF 1.38 billion, persistent barriers such as limited rights, exclusion from decision making, and restricted access to financial and technical resources continue to undermine their economic security. Effective interventions should prioritize inclusive governance, strengthen capacity, and address institutional constraints. By fully integrating women into restoration planning and management, projects can enhance ecosystem resilience while improving the livelihoods of those most dependent on these resources.

The findings from this assessment offer valuable insights for a range of stakeholders involved in the management and development of Sine-Saloum's ecosystems.

- For **Marine Conservation Zones**, this analysis makes a strong case for mangrove restoration that deliberately enhances ecosystem services, such as flood protection and carbon storage, while generating tangible social, economic, and environmental benefits for local communities. By integrating these multiple values into adaptation budgets and planning processes, project designers can achieve a clearer understanding of implementation needs and secure long-term returns for both people and nature.
- **Environmental agencies and public authorities** can use these findings to show pathways for (and highlight progress in) implementing mangrove restoration programs—a key priority of Senegal's National Adaptation Plan (NAP). The Natur'ELLES mangrove restoration initiative directly supports Senegal's overarching coastal adaptation vision, as introduced in the National Adaptation Plan for the Coastal Zone of Senegal (MEDD, 2022)—a productive, diversified, attractive, clean, and climate-resilient coastline with coastal communities benefitting from available resources while preserving marine and coastal ecosystems. Mangrove restoration in Sine-Saloum operationalizes the NAP's foundational objectives by addressing coastal erosion, salinization, and livelihood vulnerability simultaneously. The project aligns with the NAP's four strategic adaptation pillars: (1) improved coastal protection and management through soft solutions (nature-based approaches rather than hard infrastructure), (2) enhanced community adaptation through livelihood diversification and reduced infrastructure vulnerability, (3) strengthened coastal governance through multi-stakeholder collaboration and inclusive decision making, and (4) improved knowledge generation and information sharing through participatory monitoring and ecosystem assessment. The SAVi methodology itself contributes to the fourth axis by generating localized evidence on adaptation effectiveness.
- For **local communities**, restoration translates into concrete livelihood improvements through paid labour in planting and maintenance, enhanced access to fishery and agricultural resources, and income diversification. Ensuring community stewardship and inclusive decision making over restoration sites is vital to equitably distribute benefits, strengthen social cohesion, and build adaptive capacity against future climate shocks.
- **Private sector actors and financiers** may find mangrove projects attractive given their strong returns across multiple revenue streams, from increased fish and crop yields to verified carbon credits and job creation. Outcome-based financing models, including public-private partnerships and carbon credits, can underwrite restoration and ongoing management. By sharing risks and rewards, these mechanisms might align commercial interests with long-term ecosystem and community well-being.

In summary, Senegal's mangrove restoration demonstrates clear positive net benefits and strong social returns on investment across climate scenarios and extreme weather events.

Embracing NBI projects will enhance coastal protection, foster socio-economic development, and build resilience against escalating climate impacts.

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Appendix A. Further Results

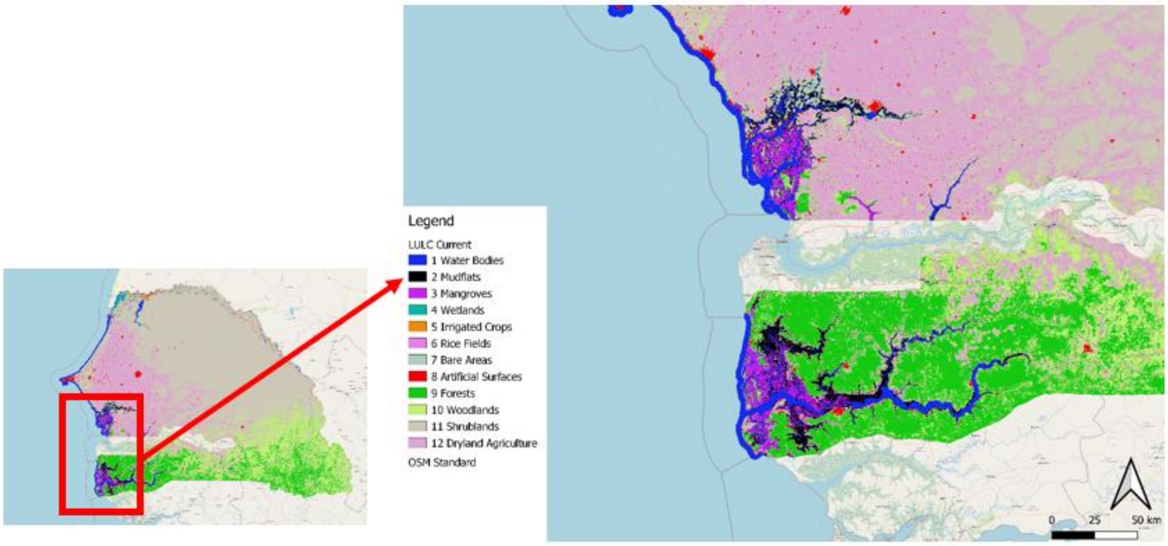
Spatial Analysis

The spatial analysis aims to assess how the NBI performs in the local context by leveraging geographic information system (GIS) data and spatially explicit models. These tools, such as the Integrated Valuation of Environmental Services and Trade-offs (InVEST[14]) model, allow us to quantify, map, and value the ecosystem services provided by natural systems, which include regulating, provisioning, cultural, and supporting services. The spatial models help identify where these services are generated and how they would shift under various land-use scenarios. This spatial information is essential for determining the value of NBI interventions across different scales, from individual urban areas to entire landscapes, and provides critical input for the integrated CBA.

Land-Cover Map

We used a land-cover map from NASA at 30 m resolution, (i.e., covers October 2022 to May 2023), as the primary input for the InVEST suite of models.

Figure A1. Land-cover map

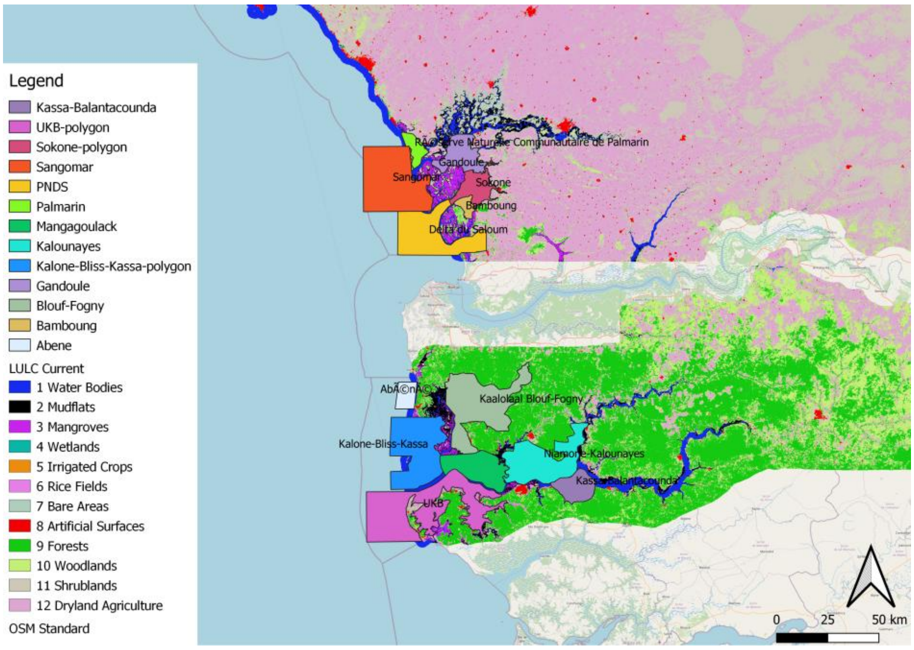


Source: InVEST.

The study areas of this analysis are shown in Figure A2.

[14] Available at https://naturalcapitalproject.stanford.edu/software/invest.

Figure A2. Study area

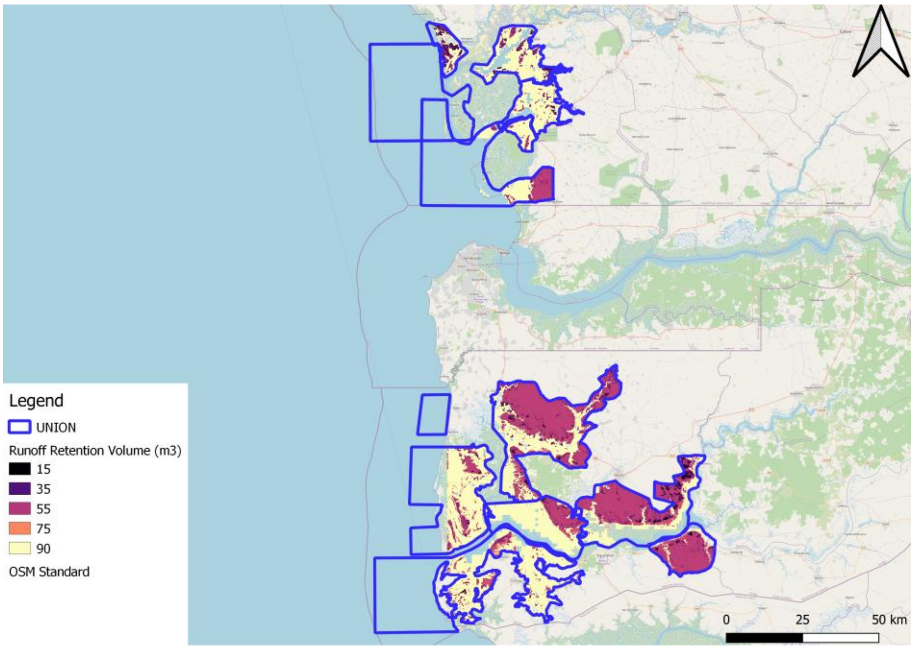


Source: InVEST.

Flood Risk

The model calculates the runoff reduction, i.e., the amount of runoff retained per pixel compared to the storm volume.

Figure A3. Flood risk area



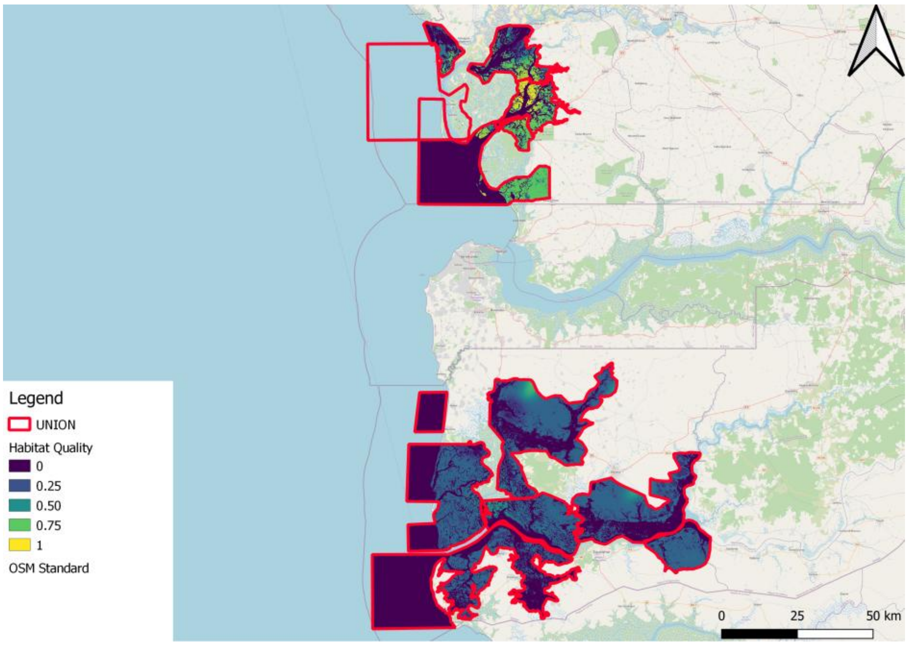
Source: InVEST.

The InVEST flood risk model indicates that retention volume under the current scenario amounts to 291,305,159 m3.

Habitat Quality

The model estimates the extent of habitat quality across the study area.

Figure A4. Habitat quality area



Source: InVEST.

The InVEST habitat quality model indicates that the mean of habitat quality in the study area under the current scenario is equal to 0.17, on a scale from 0 (lowest level of HQ) to one (highest level of HQ).

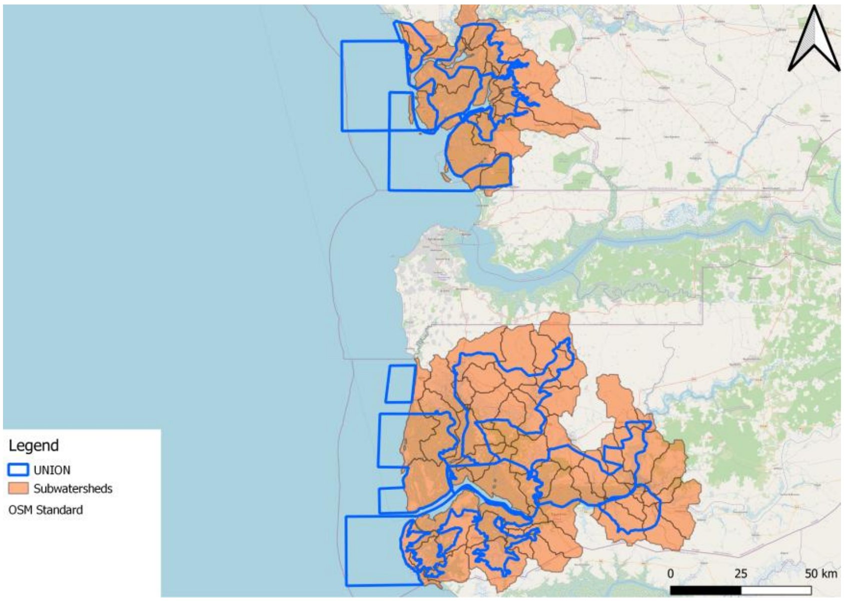
Sediment Export

The model estimates the tonnes of avoided sediment exported in the study area.

The InVEST sediment export model indicates that the tonnes of sediments exported in the study area under the current scenario amounts to 205,610 tonnes.

No relevant spatial outputs are generated by this model. The models need the geometries of the sub-watersheds found in the study area to run, and the exported sediments are modelled for those areas.

Figure A5. Sediment export area

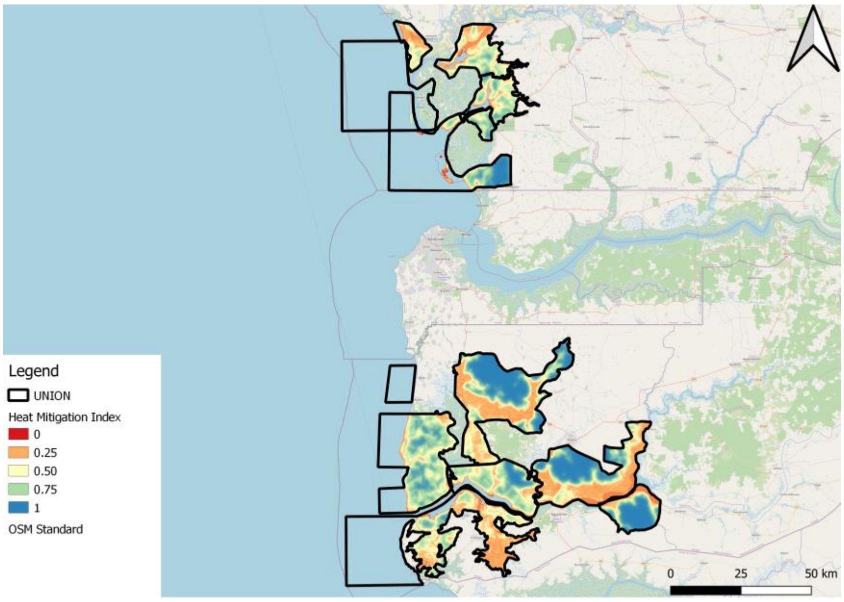


Source: InVEST.

Cooling

The InVEST cooling model indicates that temperature in the study area under the current scenario is equal to 32.58°C, considering an ambient air temperature of 30.00°C and a heat island effect of 5.00°C.

Figure A6. Cooling model area



Source: InVEST.

Methodology

Table A1. Flood regime parameters

Flood scenario	Average intensity (Intensity 1 in X)	Average recurrence interval	Annual event rate
Severe	1 in 30 years	Every 2 years	1 event per year
Moderate	1 in 30 years	Every 5 years	1 event per year

Source: Author.

Table A1 defines two flood regimes (severe and moderate) using three related metrics to describe how often and how intense flood events are expected to occur:

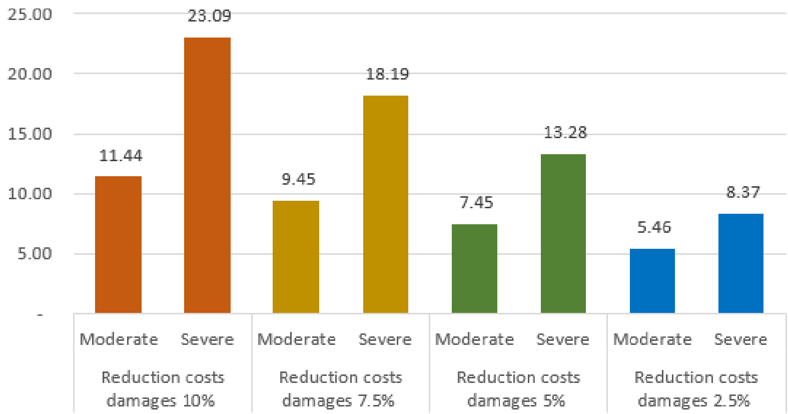
- **Average intensity (intensity 1 in X)**: “1 in 30 years” means that the flood magnitude in question, defined by a specific peak flow rate or water depth, is statistically expected to be equalled or exceeded once every 30 years on average. In hydrological terms, it examines long-term flow records and fits them to an extreme-value distribution, for example, Gumbel or Log-Pearson Type III, (Nasir, N. N., 2025). They then identify the flow corresponding to the 1/30 (≈3.3%) annual exceedance probability. That flow value is the “30-year flood” intensity, representing the benchmark magnitude used throughout the analysis.
- **Average recurrence interval**: This describes how frequently floods actually materialize over time. In the severe regime, a 30-year flood is assumed to recur every two years on average, reflecting factors like changing climate conditions that make large floods more common than their statistical rarity suggests. In the moderate regime, the same 30-year flood is assumed to recur every five years, representing a lower overall flood frequency.
- **Annual event rate**: This translates the recurrence interval into expected annual occurrences in years when flooding happens. For both regimes, the model assumes that in each year where flooding occurs, there will be exactly one flood event of the specified intensity.

CBA Results

Figure A7 compares the net present value (NPV) of the project across four flood-frequency scenarios (less severe: five-year floods; severe: two-year floods) and four levels of infrastructure damage cost reduction (10%, 7.5%, 5%, 2.5%). Under the most optimistic conditions (five-year floods and 10% cost reduction), the NPV reaches XOF 11,443,046,154. Under the same cost-reduction rate but with more frequent severe floods, the NPV increases to XOF 23,093,310,156, reflecting greater avoided damage under frequent floods. As the assumed damage reduction falls to 7.5%, the NPVs are XOF 9,448,110,280 (less severe) and XOF 18,185,808,282 (severe). At 5% reduction, NPVs decline to XOF 7,453,174,406 and

XOF 13,278,306,407, respectively; at 2.5%, they further drop to XOF 5,458,238,532 and XOF 8,370,804,532.

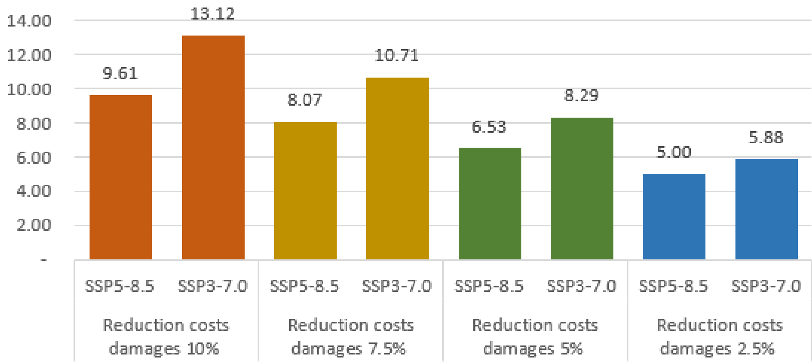
Figure A7. Net present value under flood scenarios, billion XOF



Source: Author.

Figure A8 presents NPVs under two Shared Socio-economic Pathways—SSP5-8.5 (high emissions) and SSP3-7.0 (moderate emissions)—for the same four infrastructure damage reduction rates. Under a 10% damage reduction, the NPV is XOF 9,606,237,334 (SSP5-8.5) and XOF 13,121,568,225 (SSP3-7.0). At 7.5%, NPVs are XOF 8,070,503,665 and XOF 10,707,001,833; at 5%, XOF 6,534,769,996 and XOF 8,292,435,441; and at 2.5%, XOF 4,999,036,327 and XOF 5,877,869,049. Lower emissions (SSP3-7.0) consistently yield higher NPVs due to stronger climate impacts.

Figure A8. Net present value under climate scenarios SSP5-8.5 vs. SSP3-7.0, values in billions XOF

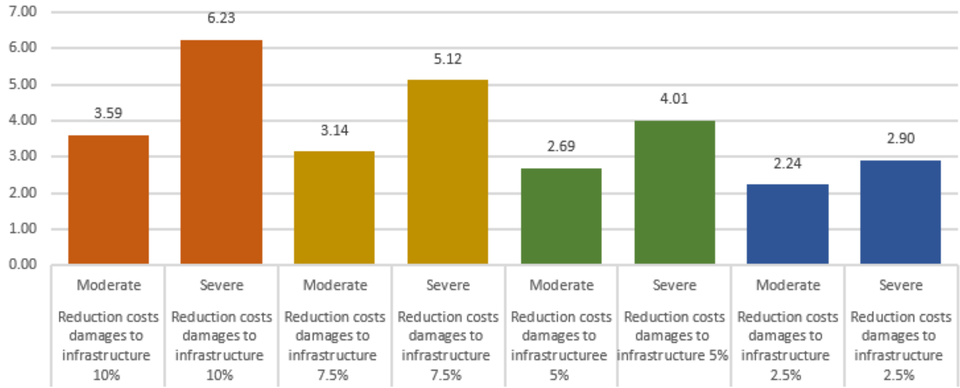


Source: Author.

Figure A9 shows the benefit-cost ratio (BCR) for each flood-frequency and damage reduction combination. Across all scenarios, BCR values exceed 2.0, indicating robust returns. The highest BCR occurs under severe (two-year) floods with 10% damage reduction, at approximately 3.59. Under less severe (five-year) floods with 10% reduction, BCR is about

3.18. As reduction rates decrease to 7.5%, 5%, and 2.5%, BCRs decline in both flood contexts but remain above 2.0 (e.g., severe floods at 2.5% reduction yield a BCR around 2.90).

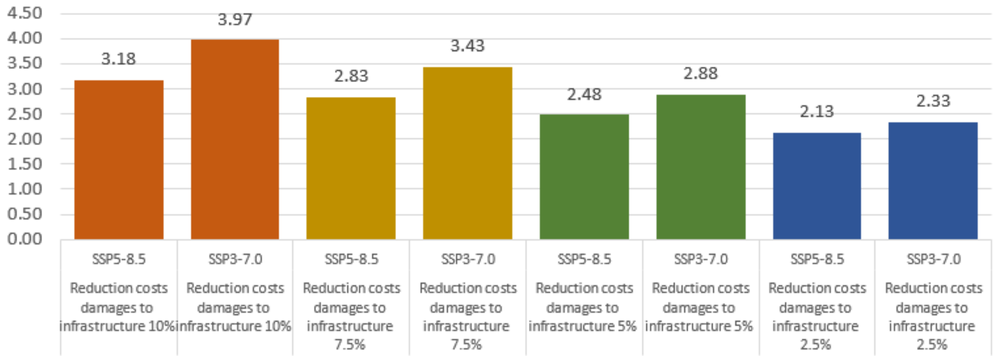
Figure A9. Benefit-cost ratio under flood scenarios



Source: Author.

Figure A10 illustrates BCR under SSP5-8.5 versus SSP3-7.0 for the four damage reduction rates. Under 10% reduction, BCR is 3.18 (SSP5-8.5) and 3.43 (SSP3-7.0). For 7.5%, values are around 2.48 and 2.88; for 5%, about 2.13 and 2.33; and for 2.5%, approximately 1.82 and 2.13. Higher BCRs under SSP3-7.0 reflect greater cost-effectiveness when emissions and associated impacts are lower.

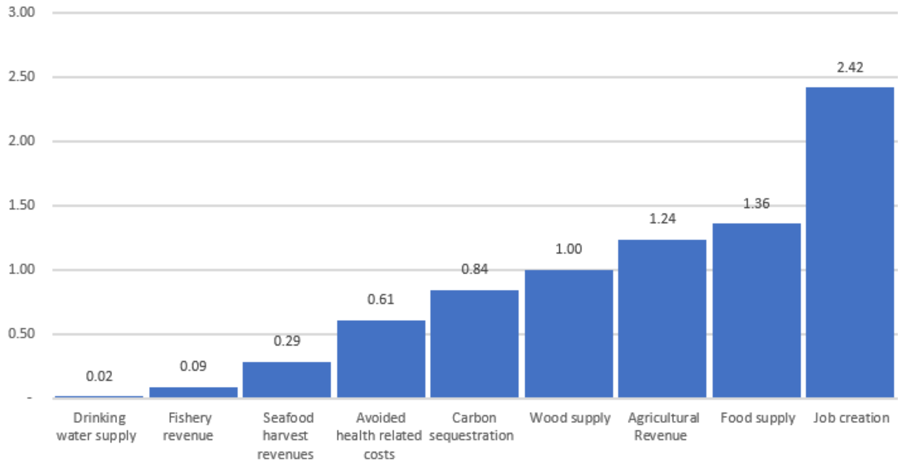
Figure A10. Benefit-cost ratio under SSP Scenarios, values in billions CFA



Source: Author.

Figure A11 ranks nine benefits and avoided costs categories by magnitude (in billions XOF): job creation (2.42), food supply (1.36), agricultural revenue (1.24), wood supply (1.00), carbon sequestration (0.84), avoided health costs (0.61), seafood harvest revenues (0.29), fishery revenue (0.09), and drinking water supply (0.02). Total benefits sum to XOF 15.86 billion, highlighting that job creation and food supply are the largest non-infrastructure gains.

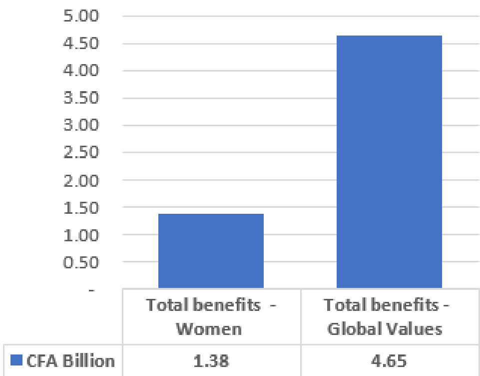
Figure A11. Distribution of benefits (excluding avoided costs to infrastructure damage), values in billions XOF



Source: Author.

Figure A12 shows total gender-differentiated benefits: women receive XOF 1.38 billion, whereas the global total benefits for all stakeholders amount to XOF 4.65 billion. This underscores that women capture roughly 30% of overall project benefits.

Figure A12. Total benefits for women versus total benefits (global values), values in billions XOF



Source: Author.

Appendix B. Modelling Assumptions

Implementation Costs (CAPEX) - Reforestation area (ha)

Restoration area represents the total number of hectares planted in each project zone per year. Planting targets were defined by IUCN data for four sites—APAC Kolou Ndig, RNC Palmarin, AMP Sokone, and AMP Bamboung—and then summed to yield the annual restoration area. In 2024, planting covers 4.0 ha at Kolou Ndig, 0 ha at Palmarin, 22.0 ha at Sokone, and 5.0 ha at Bamboung, for a total of 31.0 ha. In 2025, targets increase to 15.0 ha, 10.0 ha, 15.0 ha, and 15.0 ha across the same sites, totalling 55.0 ha. In 2026, planned plantings are 10.0 ha, 10.0 ha, 15.0 ha, and 10.0 ha, for 45.0 ha in all.

Unit Planting Cost (CFA/ha)

The unit planting cost contains all expenses required to establish one hectare of mangrove forest, including seedlings, labour, site preparation, and delivery (based on information provided by IUCN). This cost is held constant at XOF 350 000 per hectare across all years.

Restoration Implementation Cost (CFA)

Implementation costs are calculated by multiplying the annual restoration area by the unit planting cost. For example, in 2024 the total cost equals 31.0 ha × XOF 350,000/ha = XOF 10,850,000. Similarly, in 2025 the cost is 55.0 ha × CFA 350 000/ha = 19 XOF 250 000, and in 2026 it is 45.0 ha × XOF 350,000/ha = XOF 15,750,000. These yearly costs feed directly into the CBA as the capital expenditures (CAPEX) for restoration activities.

Maintenance Costs (OPEX)

Operations and maintenance costs cover all annual activities required to sustain restored and protected areas (i.e., monitoring, seedling care, patrols, community management, etc.).

Conserved Area (ha)

The total area under conservation management each year is the sum of active hectares across four sites: APAC Kolou Ndig, RNC Palmarin, AMP Sokone, and AMP Bamboung.

- 2024: 150 ha + 2,500 ha + 1,000 ha + 1,500 ha = 5,150 ha
- 2025: 250 ha + 4,000 ha + 2,000 ha + 2,500 ha = 8,750 ha
- 2026: 362 ha + 5,000 ha + 3,000 ha + 4,500 ha = 12,862 ha

Unit Conservation Cost (CFA/ha/year)

The average annual cost to maintain one hectare of restored mangrove is assumed to be XOF 20,000/ha/year.

Annual OPEX (CFA)

Operations and maintenance costs are calculated by multiplying the conserved area by the unit cost:

- 2024: 5,150 ha × XOF 20,000/ha/year = XOF 103,000,000
- 2025: 8,750 ha × XOF 20,000/ha/year = XOF 175,000,000
- 2026: 12,862 ha × XOF 20,000/ha/year = XOF 257,240,000

Cost of Flood Damage

Cost of Flood Damage – Public Buildings

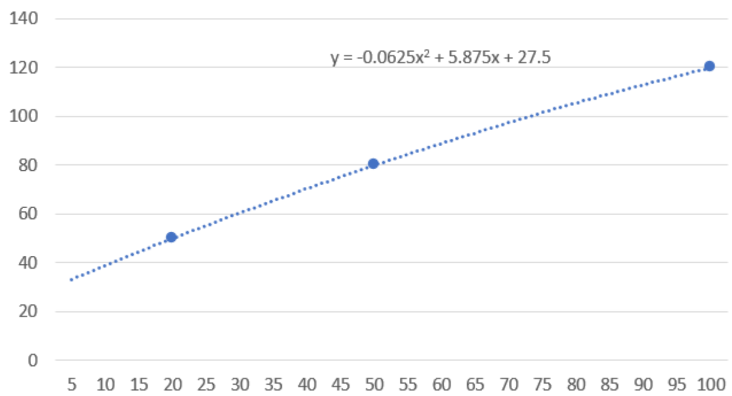
Under the baseline scenario, the cost of flood damage to public buildings in the Foundiougne and Fatick districts occurs only when floods occur. Based on the flood frequency, we assume homogeneous distribution of flood occurrence across 2024 to 2050. In other words, if there is a flood frequency of one flood every *y* years then the flood occurrence marker would jump to one every *y* years throughout. Note that the flood frequency parameter is chosen for each simulation.

With three flood lines (1:20, 1:50, 1:100), we extrapolated a function between the flood intensity and the number of buildings impacted. For public buildings, this function is a polynomial defined as follows:

$$f_1 (x)= -0.0625 x^2 +5.875 x-27.5$$

Where $f_1 (x)$ is the number of public buildings affected when a flood occurs, and x is the flood intensity. Graphically, this function looks as follows:

Figure B1. Public buildings



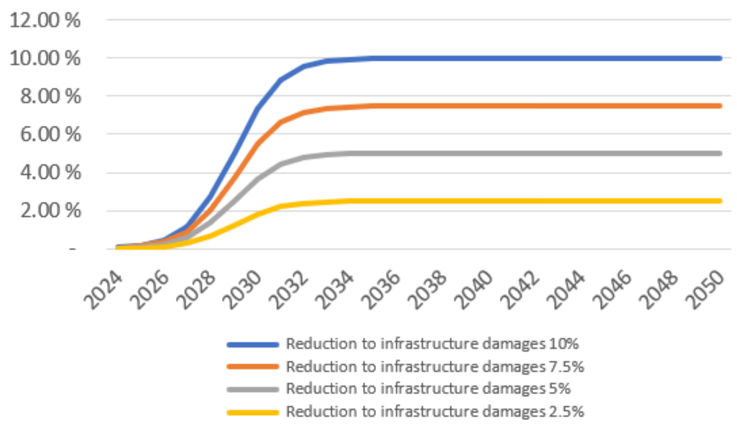
Source: Author.

Finally, we assumed a value of XOF 450,000 per square metre of buildings for which we assumed damage of 50%. In other words, we used the following equation:

"Public building costs when a flood occurs" = "Number of public buildings affected per flood" × "Average size of affected public buildings" × "Unit value of public building" × "Percentage of public buildings damage" = f_1 (x)= -0.0625 x^2 +5.875 x-27.5

Under the NBI scenario, we assumed four levels of flood damage reduction to infrastructure: 10%, 7.5%, 5%, and 2.5%, reflecting the range of intervention effectiveness in lowering flood-related damage. We then assumed it would take 10 years to achieve this percentage decrease given the timeline of implementation. In other words, we assumed the following materialization over time:

Figure B2. Flood damage reduction to infrastructure



Source: Author.

Cost of Flood Damage – Residential Buildings

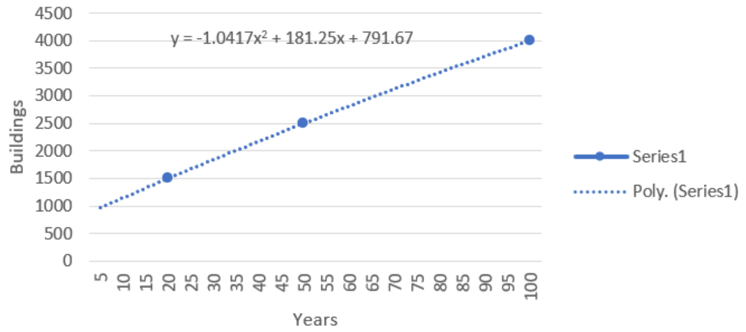
Under the baseline scenario, the cost of flood damage to residential buildings in the Foundiougne and Fatick districts occurs only when a flood occurs. Based on the flood frequency, we assume homogeneous distribution of flood occurrence across 2024 to 2050. In other words, if there is a flood frequency of one flood every *y* years then the flood occurrence marker would jump to one every *y* years throughout. Note that the flood frequency parameter is chosen for each simulation.

With three flood lines (1:20, 1:50, 1:100), we extrapolated a function between the flood intensity and the area impacted. For residential buildings, this function is a polynomial defined as follows:

f_1 (x)= -1.0417 x^2 +181.25 x-791.67

Where f_1 (x) is the area of residential buildings affected when a flood occurs, measured in number of buildings, and *x* is the flood intensity. Graphically, this function looks as follows:

Figure B3. Residential buildings



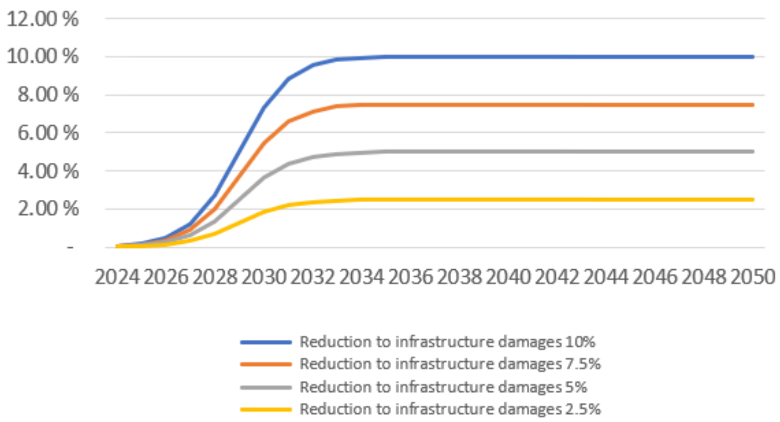
Source: Author.

Finally, we assumed a value of XOF 360,000 per square metre of buildings for which we assumed damage of 50%. In other words, we used the following equation:

"Residential buildings costs when a flood occurs" = Number of residential buildings affected per flood" × "Average size of affected buildings" × "Unit value of residential building" × "Percentage of residential buildings damage" = f_1 (x)= -1.0417 x^2 +181.25 x-791.67

Under the NBI scenario, we assumed four levels of flood damage reduction to infrastructure: 10%, 7.5%, 5%, and 2.5%, reflecting the range of intervention effectiveness in lowering flood-related damage. We then assumed it would take 10 years to achieve this percentage decrease given the timeline of implementation. In other words, we assumed the following materialization over time:

Figure B4. Flood damage reduction to infrastructure



Source: Author.

Cost of Flood Damage – Roads

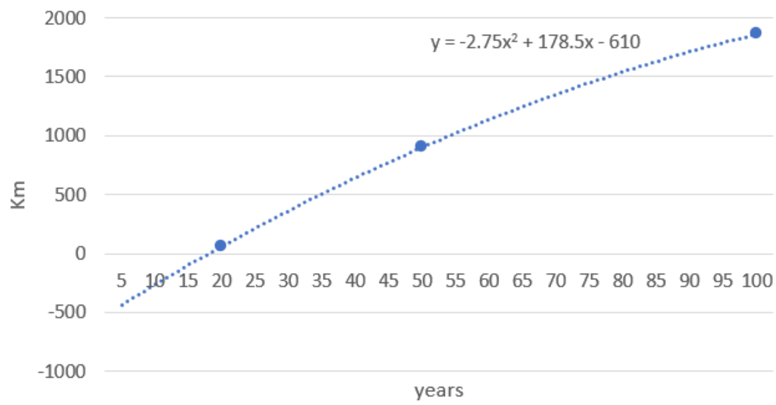
Under the baseline scenario, the cost of flood damage to roads in the Foundiougne and Fatick districts occurs only when a flood occurs. Based on the flood frequency, we assume homogeneous distribution of flood occurrence across 2024 to 2050. In other words, if there is a flood frequency of one flood every *y* years then the flood occurrence marker would jump to one every *y* years throughout. Note that the flood frequency parameter is chosen for each simulation.

With three flood lines (1:20, 1:50, 1:100) we extrapolated a function between the flood intensity and the kilometres of road impacted. For roads, this function is a polynomial defined as follows:

f_1 (x)= -2.75 x^2 +178.5 x-610

Where f_1 (x) is the roads affected when flood occurs, measured in kilometres of roads, and *x* is the flood intensity. Graphically, this function looks as follows:

Figure B5. Roads



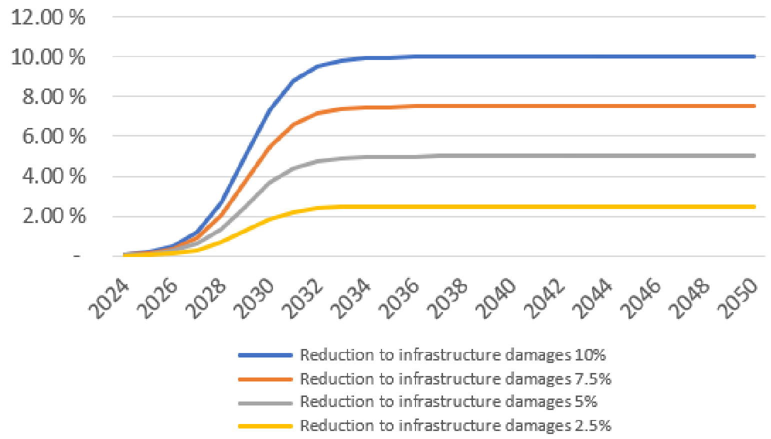
Source: Author.

Finally, we assumed a value of XOF 350,000 per square metre of roads. In other words, we used the following equation:

"Residential buildings costs when flood occurs" = "Number of km of roads affected per flood" × "Unit value of damaged road per kilometers" = f_1 (x)= -2.75 x^2 +178.5 x-610

Under the NBI scenario, we assumed four levels of flood damage reduction to infrastructure: 10%, 7.5%, 5%, and 2.5%, reflecting the range of intervention effectiveness in lowering flood-related damage. We then assumed it would take 10 years to achieve this percentage decrease given the timeline of implementation. In other words, we assumed the following materialization over time:

Figure B6. Flood damage reduction to infrastructure



Source: Author.

Avoided Health-Related Costs

Under the baseline scenario, health-related costs are calculated based on household (survey data from Socodevi). Using monthly direct health expenses of XOF 25,000 per household (Socodevi survey), we assume an annual cost of XOF 60,000 per household (XOF 25,000/month × 12 months). Given that climate and environmental factors contribute to health problems, we assume 20% of total health expenses are attributable to these issues.

Annual health cost per households × number of households in Fatick and Foundiougne = XOF 1,544,285,556

Using survey data showing 77,222 households in Fatick and Foundiougne with an average household size of 12 persons, and considering that women represent 30.8% of the population (3.7 women per household), we calculate the following equation:

"Health-related costs for women" = "Number of households" × "Annual health expenses per household" × "Percentage attributable to climate factors" × "Percentage of women in population"

= 25,738 households × XOF 60,000/year × 20% × 30.8% = XOF 476,154,713/year

Note: The number of households was adjusted to 25,738 (approximately 1/3 of the total 77,222) to avoid overestimation and reflect a more conservative estimate for the project area.

Under the NBI scenario, we assume a 2.5% reduction in health-related costs due to improved air quality and reduced pollution from mangrove restoration. We assume it would take 23 years to achieve this 2.5% decrease given the gradual nature of health improvements. The model applies a linear change rate of 0.20 per year to capture this temporal transition in health cost savings.

Fishery Revenue

Under the baseline scenario, fishery revenues are estimated using national artisanal fishery data and regional production volumes from Fatick and Foundiougne. Based on USDA, 2021, Senegal's artisanal fishery sector produced 348,208 tonnes valued at USD 24.89 million, yielding an average price of USD 71.48 per tonne. Converting to local currency using an exchange rate of 642 CFA/USD (January 2025) , the unit value becomes XOF 45,903 per tonne. Regional production data shows 17,788 tonnes per year in Fatick (Socodevi survey) and 9,633 tonnes per year in Foundiougne (questionnaire survey), totalling 27,421 tonnes annually. Assuming 90.7% of production is destined for sale (Socodevi survey), marketable volume equals 24,871 tonnes per year.

"Total fishery revenue" = "Unit value per tonne" × "Volume destined for sale"

= XOF 45,903/tonne × 24,871 tonnes/year = XOF 1,141,642,872/year

For gender analysis, we assume women manage 40% of fish processing activities (10,968 tonnes) and sell 50% of their processed fish (5,484 tonnes). Using the following equation:

"Fishery revenue for women" = "Volume sold by women" × "Unit price per tonne"

= 5,484 tonnes/year × XOF 45,903/tonne = XOF 251,740,435/year

Under the NBI scenario, we assume mangrove restoration will increase fishery productivity by 3.0% due to improved nursery habitats and ecosystem health. We assume it would take 25 years to achieve this 3.0% increase given the time required for ecosystem recovery and fish population growth. The model applies a linear change rate of 0.20 per year to capture this gradual improvement in fishery revenues.

Agricultural Revenue

Under the baseline scenario, agricultural revenues are calculated based on regional production data from DAPSA and ANSD surveys for Fatick and Foundiougne. For rice production, cultivated areas are estimated at 6,980 ha in Fatick and 2,000 ha in Foundiougne (DAPSA Agricultural Survey 2022-2023), with an average yield of 2,500 kg/ha/year (JICA report). Assuming 95% of production is destined for sale at XOF 400/kg local price, the calculation follows:

"Rice agricultural revenue" = "Total cultivated area" × "Average yield" × "Percentage sold" × "Unit price"

= 8,980 ha × 2,500 kg/ha/year × 95% × XOF 400/kg = XOF 8,531,000,000/year

Similarly, for maize production totalling 56,772 tonnes (ANSD Fatick survey), with 70% sold at XOF 393/kg (Socodevi data), revenues equal XOF 15,618,098,244/year. Millet production from 39,218 ha at 1,324 kg/ha/year yield, with 80% sold at XOF 204/kg, generates XOF

8,474,099,942/year. Sorghum production of 39,477 tonnes with 80% sold at XOF 375/kg yields XOF 11,843,040,000/year. Watermelon production of 39,900 tonnes with 80% sold at XOF 620/kg generates XOF 19,790,400,000/year.

Total baseline agricultural revenues sum to XOF 64,256,638,186/year.

For gender analysis, women's participation varies by crop: 30% of rice production, 20% of maize, 70% of millet, 60% of sorghum, and 50% of watermelon. Women sell different percentages of their production (40% for rice, 30% for maize, 75% for millet, 70% for sorghum, 65% for watermelon), resulting in total women's agricultural revenues of XOF 43,986,340,266/year.

The difference in sorghum prices reflects different market channels. The general revenue calculation uses a bulk/farm-gate price, while the gender-disaggregated estimate reflects women's participation in local retail or value-added sales, where smaller quantities may be sold at higher prices. Therefore, this value should be interpreted as an indicative estimate of women's sorghum-related market income, rather than a direct proportional share of total sorghum revenue.

Under the NBI scenario, mangrove restoration is assumed to increase agricultural productivity by 2.3% due to improved soil quality, water retention, and reduced salinity intrusion. This increase materializes gradually over 30 years with a linear change rate of 0.20 per year, reflecting the time needed for ecosystem services to fully benefit agricultural production.

Seafood Harvest Revenues

Under the baseline scenario, annual oyster-harvesting revenues for women are estimated using participation, productivity, and market data from ICD-Afrique and field hypotheses:

"Annual shellfish revenue for women" =

"Number of women involved" × "Annual harvest per woman" × "Share sold" × "Unit price"

With 2,000 women across Fatick and Foundiougne [ICD-Afrique project data, 2018] each harvesting 8kg per day over 120 days (1 pot = 1 kg hypothesis) for an annual yield of 960 kg per woman; assuming 95% of oyster harvest is sold at XOF 500/kg, the calculation is:

= 2,000 women × 960 kg/woman × 0.95 × XOF 500/kg

= XOF 912,000,000/year

Under the NBI scenario, improved coastal ecosystems are assumed to boost women's shellfish harvest revenues by 10%. This gain phases in over 15 years with a constant annual slope of 0.15, reflecting gradual restoration of oyster beds and market access improvements.

Drinking Water Supply

In the baseline scenario, potable-water supply volumes and revenues are estimated from existing subscriber consumption rates and subscriber counts, without any additional interventions. This approach reflects current network efficiency and tariff structures as reported by Socodevi surveys.

First, we take the average annual consumption per connected household from the ANSD's 2022 to 2023 SES for each department:

Fatick: 165 m³ per subscriber per year

Foundiougne: 221 m³ per subscriber per year

Next, subscriber totals—drawn from the ANSD's 2020 to 2021 SES—are held constant:

Fatick: 7,069 subscribers

Foundiougne: 3,397 subscribers

Annual volumes distributed in each department are then calculated as:

"Total volume" = "Average consumption rate" × "Number of subscribers"

Fatick: 165 m³/yr × 7,069 subs = 1,166,385 m³/yr

Foundiougne: 221 m³/yr × 3,397 subs = 750,737 m³/yr

Summing these yields a regional baseline volume of 1,917,122 m³ per year.

To monetize this service, the region's current water tariff of XOF 250/m³ (pS-Eau, April 2024) is applied:

Annual revenue = 1,917,122 m³ × XOF 250/m³ = XOF 479,280,500 per year.

Under the NBI scenario for drinking-water supply, ecosystem interventions are assumed to yield a net 3% increase in available potable water. This gain is modelled to phase in linearly over 25 years, using an annual change slope of 0.20, reflecting the gradual development of ecosystem services that enhance recharge, reduce losses, and stabilize source yields.

Food Supply

Under the baseline scenario, food provisioning values are computed from sector revenues and assumed sale shares:

First, fisheries revenues of XOF 251,740,435/year (Socodevi survey) yield provisioning value as:

"Provisioning–fisheries" = XOF 251,740,435/yr × 90.7% = XOF 25,812,415/yr

For crop revenues and sale shares:

- Rice: XOF 8,531,000,000/yr × (1%–95%) = XOF 449,000,000/yr
- Maize: XOF 15,618,098,244/yr × (1%–70%) = XOF 6,693,470,676/yr
- Millet: XOF 8,474,099,942/yr × (1%–80%) = XOF 2,118,524,986/yr
- Sorghum: XOF 11,843,040,000/yr × (1%–80%) = XOF 2,960,760,000/yr
- Watermelon: XOF 19,790,400,000/yr × (1%–80%) = XOF 4,947,600,000/yr

For shellfish harvest (women's income): XOF 912,000,000/yr × (1%–95%) = XOF 48,000,000/yr

Summing all provisioning values yields a total baseline food provisioning of XOF 17,243,168,077/yr.

Under the NBI scenario, nature-based interventions are assumed to enhance food provisioning by a net 3.0% once mature. This gain phases in linearly over 25 years with an annual change slope of 0.20, reflecting gradual ecosystem service development. At full maturity, provisioning values increase by 3% above baseline.

Wood Supply

Under the baseline scenario, household firewood provisioning is calculated as follows:

Annual harvest: 551 kg/household × 77,222 households = 42,549,322 kg/year

Annual value: 42,549,322 kg × XOF 150/kg = XOF 6,382,398,300/year

Thus, firewood provisioning generates XOF 6.38 billion per year.

Under the NBI scenario, sustainable management practices (e.g., community woodlots, agroforestry buffers) are assumed to boost firewood provisioning by 5.0% once fully implemented. This gain phases in linearly over 25 years at an annual change rate of 0.20.

Job Creation

Under the NBI scenario, project staffing and gender-sensitive compensation are derived from restoration and conservation cost profiles (based on Socodevi estimations and data surveys):

Restoration salaries are calculated as 40% of construction costs per hectare each year:

- 2024: XOF 10,850,000/ha × 40% = XOF 4,340,000/ha
- 2025: XOF 19,250,000/ha × 40% = XOF 7,700,000/ha

- 2026: XOF 15,750,000/ha × 40% = XOF 6,300,000/ha

O&M salaries are 55% of annual operations and maintenance costs:

- (XOF 103,000,000 + XOF 175,000,000 + XOF 257,240,000) × 55% = XOF 294,382,000 total
- Total annual salaries in 2026:
- XOF 300,000 (restoration) + XOF 294,382,000 (O&M) = XOF 300,682,000

For gender-sensitive indemnities, compensation is allocated per female participant at XOF 5,000 each:

- Restoration: 370 women × XOF 5,000 = XOF 1,848,792/year
- Conservation: 261 women × XOF 5,000 CFA = XOF 1,305,824/year

Carbon Sequestration

Under the NBI scenario, restored mangrove stands are assumed to sequester carbon at the young-mangrove rate of 14.60 t CO_2/ha/year (data provided by Tayo). Restoration areas from Socodevi data accrue as follows:

- 2024: 31 ha × 14.60 t CO_2/ha/year = 452.60 t CO_2
- 2025: 55 ha × 14.60 t CO_2/ha/year = 803.00 t CO_2
- 2026: 45 ha × 14.60 t CO_2/ha/year = 657.00 t CO_2

The social cost of carbon is set at USD 50/t CO_2 (Rennet, K, 2025) converted at 557.29 CFA/USD (XE, 02/07/2025), yielding XOF 27 864.57/t CO_2.

Annual sequestration values are therefore:

- 2024: 452.60 t CO_2 × XOF 27 864.57/t CO_2 = XOF 12,611,505.51
- 2025: 803.00 t CO_2 × XOF 27 864.57/t CO_2 = XOF 22,367,876.71
- 2026: 657.00 t CO_2 × XOF 27 864.57/t CO_2 = XOF 18,309,114.49

After 2026, with 131 ha of mature mangroves sequestering at the same rate, total annual sequestration becomes:

- 131 ha × 14.60 t CO_2/year = 1 912.60 t CO_2/year,
- valued at 1 912.60 t CO_2 × XOF 27,864.57/t CO_2 = XOF 53,293,781/year.

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